

PHYSICS IX-X

Part - II



Punjab Textbook Board, Lahore.

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PHYSICS X

Part II



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MESSAGE OF CHIEF MINISTER (PUNJAB)

The progress in education is at its peak in the present day. The quality of education is the main distinction of the developed nations. To achieve excellence in quality education, the curriculum and textbooks play the basic role. Placing main emphasis on modernization of curriculum and textbooks, proves beyond any doubt the priority given by my government to the education sector.

As for curriculum development, a team of professional experts was assembled for writing of textbooks, which will prove helpful in achieving the quality of education.

Dear students! To achieve a better standard of life, quality education plays a pivotal role. My government is trying hard to provide this base. Now it is your duty to make use of these textbooks and play your full role in the development of Pakistan.

I pray to God Almighty that the new generation, keeping in view the modern trends of education, may make progress by leaps and bounds.

(Ch. Pervez Elahi)
Chief Minister,
Punjab.

PREFACE

No nation can flourish without literacy, universal Education and particularly without scientific Education. Realising this fact, the Education Department, Government of the Punjab prepared a new Science and Mathematics curricula which has been approved by the Federal Government for implementation at the national level.

This book has been written according to the new curriculum. In order to increase the interest and curiosity in the students, the subject matter has been made more effective by adding figures and diagrams.

Since there is always a room for improvement, new ideas, fresh knowledge and information, continuous research, modern methods of teaching, national demands and aspirations and above all the wish for a change always expect the curricula to be revised and updated regularly.

The present effort is also a ring of this chain. Anyway, I hope that the teachers, the students, the parents and the experts will continuously keep us informed of their opinion about the new curriculum and the textbooks, so that we may be able to improve the next edition of this textbook.

At the end, I would like to thank the various educationists and experts who, most willingly, came forward to review our work and gave very valuable suggestions.

Above all, I thank Almighty Allah (SWTH), who provided us the opportunity and gave us the strength to undertake this work of national importance. I pray that this effort may prove to be the beginning of a new era; an era in which Science & Technology may make great progress in Pakistan and Pakistan may become at par with the developed nations. (Amin!).

(Dr. Fouzia Saleemi)
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WAVE MOTION

In this chapter you will learn:

1. Wave motion.
2. Simple harmonic motion and simple pendulum.
3. Waves and their types.
4. Waves as carriers of energy.
5. Properties of waves.
6. Stationary waves.

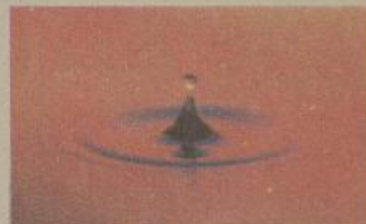
Children are often seen dropping stones in the water, while sitting by a pond, and getting amused by the waves being produced in it. Waves are not only produced on the surface of water, but when one end of a stretched rope is briskly moved up and down, waves can be seen being produced in the rope. Now-a-days, we are familiar with many different types of waves which are not visible but can be detected with sensitive equipments. Sound also reaches our ears in the form of waves. The heat and light that reaches us from the Sun, also does this in the form of waves. The broad-casting of radio and television programs are also made possible by the waves. The defects in the human body e.g., broken bones, tumors, bullets, can also be detected by a specific type of waves, known as X-rays. What are waves? How are they produced? How many types of waves are there? Answers to such questions are discussed in detail in this chapter with the aid of experimental observations.

12.1 WAVE MOTION

Experiment 1: Dip one end of a pencil at the edge of a tub containing water, rapidly move the pencil up and down vertically, the ripples spread outwards on the surface of the water (Fig. 12.1).

Place some small pieces of the cardboard or cork equally spaced, in the direction of the waves, and observe the movement of the pieces as the waves pass. You will see that every piece of cardboard moves up and down about its mean position. They are not displaced forward from their original positions along with the water waves. The motion of these pieces about their mean positions is known as "Vibratory Motion". If we examine the vibratory motion of all the pieces, it can be observed that they do not vibrate together but vibrate vertically at their own position one after the other.

In this experiment, the vibratory motion of the pencil produces a disturbance in the constituent molecules of the water, due to which they start exhibiting vibratory motion about their mean position. Then this disturbance is transferred along with the wave, and a visible water wave can be observed.



Waves on water surface

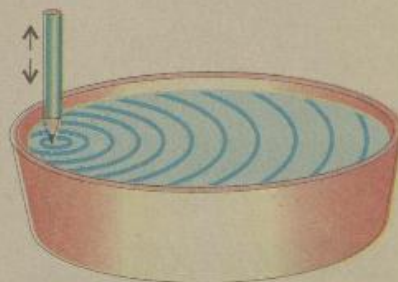


Fig. 12.1

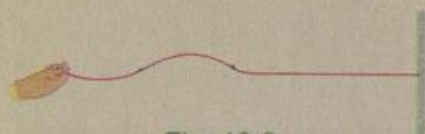


Fig. 12.2

Experiment 2: Take a string and mark it with different colours at equal intervals. Attach one end of the string with a hook and stretch the string by holding its other end in your hand. Start oscillating, the horizontally stretched string, vertically up and down briskly, waves can be seen as shown in the Fig. 12.2. If the coloured markings are carefully observed, you will see that they are vibrating about their mean positions as the waves travel down the string. At a particular time, it can be observed that the marking rather than being in the same state of vibration, are in different state along their vibratory path.

We can conclude from this experiment that by moving the free end up and down a disturbance is generated and transferred to the other parts of the string, which one after the other start vibrating about their mean position. Thus disturbance travels along with the string in the form of waves.

From the above performed experiments, we can define wave motion as follows:

Wave motion in a medium is due to the generated disturbance which causes the constituent particles to repeat its to and fro motion about its mean position in equal interval of time, and this disturbance is passed over from one end of the medium to the other.

From the above experiments we also observe the particles of the medium play an important role in the generation of waves. They perform a special type of motion known as Simple Harmonic Motion. We will study it in detail.

12.2 SIMPLE HARMONIC MOTION

We know that when a body moves to and fro about its mean position along a fixed axis, with equal intervals of time, its motion is known as vibratory motion e.g., the motion of pendulum, mass attached to a spring, the motion of cardboard pieces along with the water waves etc. Simple harmonic motion is a vibratory motion which can be explained by the following examples.

Mass Attached to a Spring

To explain the simple harmonic motion, consider the motion of a mass attached with a spring. As shown in Fig. 12.3, a spring is placed on a smooth and horizontal surface. Its one end is attached to a firm support and a mass m is attached to its other end (Fig. 12.4-a). There is no extension in the spring in this state. Such a state or position of mass is called its equilibrium position. If an external force F_{ext} is exerted on the mass towards right, the length of the spring increases by an amount x , and the mass moves from its initial position 'O' to position 'A'. According to Hooke's law, the

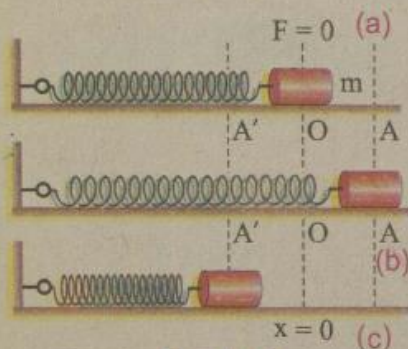


Fig. 12.3

external force F_{ext} acting on the spring is directly proportional to the increase in length x of the spring i.e.,

$$F_{ext} \propto x$$

or $F_{ext} = kx$ (12.1)

Here k is a constant, which is called the spring constant. The value of k can be obtained from Eq. 12.1 as:

$$k = F_{ext} / x$$

The ratio of the external force acting on a spring to the increase in its length is called the spring constant. Its unit is Nm^{-1} .

Under the influence of the external force, the length of the spring increases. After releasing this force, spring moves towards its equilibrium position. This motion of the spring is due to the restoring force (Fig. 12.3-b), which is a characteristic of the spring. During the motion, if the displacement of the mass m is x then restoring force will be:

$$F = -kx$$
 (12.2)

If now the mass m is let free, it starts moving towards the point O. Using Newton's 2nd law, the acceleration a of the mass m can be found out as:

$$a = \frac{F}{m} = \frac{-kx}{m}$$
 (12.3)

Since k/m is a constant, therefore

$$a \propto -x$$

This means that the acceleration of the body is directly proportional to its displacement x from the mean position O and is always directed towards the mean position O. As the mass m moves towards the point O its displacement x goes on decreasing. Resultantly, the acceleration a of the body also decreases. On reaching the point O, x becomes zero and so the acceleration a of the mass m also reduces to zero. But it may be noted that its velocity is maximum at this point. Due to inertia, the mass m does not stop at the point O but continues its motion towards left till it reaches the point A'. During this motion, the spring is now compressed. Now the restoring force and the acceleration due to it, are opposite to the motion of the mass m . This means that the acceleration of the mass m is still directed towards the point O. So the velocity of the mass m again starts decreasing as it passes the point O and finally becomes zero as it reaches the point A'. After coming to rest at the point A' the body again returns to the point O under the action of the restoring force. This process continues and the body m keeps on vibrating between the points A and A'. The motion of a mass attached to a spring is known as "Simple Harmonic Motion".

Mathematically, it can be proved that the time period T of the simple harmonic motion of a mass attached to a spring can be given by the following equation:

$$T = 2\pi \sqrt{\frac{m}{k}} \quad \dots\dots\dots (12.4)$$

Simple Pendulum

A simple pendulum consists of a single isolated bob suspended from a frictionless support by a light inextensible string. In equilibrium, the pendulum is held stationary in a vertical position (Fig. 12.4) and its bob is at O. If the bob is disturbed from O to a point A, it will start moving towards its mean position under the action of one component of gravitational force. But at point O the velocity of the bob is maximum and due to the inertia it passes by the mean position towards the other end. But now the velocity of the bob decreases, and becomes zero as it reaches at point B. The bob starts its motion from point B towards O and passes through O and reaches at point A. Thus, the bob continues its motion in between the points A and B.

It is evident from the above description that as the speed increases while moving from point A to O, the acceleration of the bob is towards O. Its acceleration remains towards point O during the motion from point O to B because now the speed decreases. It means the acceleration of the bob always directed towards the mean point O. We can prove mathematically that the acceleration of the bob is directly proportional to the displacement from equilibrium position. Hence the characteristics of the motion of the simple pendulum is like simple harmonic motion. Therefore, we conclude that the motion of the simple pendulum is also simple harmonic motion.

Now we shall discuss some terms associated with simple harmonic motion. Point O is called mean position or equilibrium position whereas the point A or B is called extreme position. The distance from point O to A or O to B is called amplitude of the vibration. Distance of position of bob between O and A (or O and B) from O is called displacement. When the bob after moving from point A to B comes back to A it is said to complete one vibration. The time required to complete one vibration is called time period of the pendulum. It has been observed through experiments that the time period of the simple pendulum does not depend on its mass and amplitude. It can be proved mathematically that if the amplitude of the simple pendulum is not too large, then its time period T can be determined from the following equation:

$$T = 2\pi \sqrt{\frac{\ell}{g}} \quad \dots\dots\dots (12.5)$$

where ℓ is the length of the pendulum which is equal to the distance between the point of suspension to centre of the bob and g is the acceleration due to gravity.

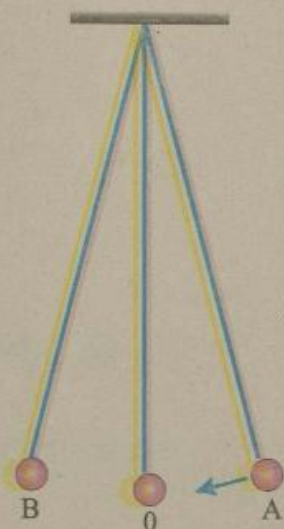


Fig. 12.4

At position O, the bob is at the lowest position of the motion. Therefore, at this position its potential energy will be minimum and kinetic energy will be maximum. Hence, its velocity will be maximum at the mean position. The bob is at highest level at position A or B therefore, the potential energy will be maximum and kinetic energy will be minimum i.e., zero. At any point in between the extreme and mean positions, the energy of the bob is partly potential and partly kinetic. However during vibration the total energy remains constant.

In simple harmonic motion, a body repeats its to and fro motion, in equal intervals of time, about its fixed mean position. Now we can sum up the characteristics of S.H.M. as follows:

1. A body executing simple harmonic motion, always vibrates about its position of equilibrium.
2. Its acceleration is always directed towards its mean position.
3. Its acceleration is directly proportional to its displacement from the mean position i.e., $a = 0$ at the mean position, and $a \dots$ at extreme positions.
4. Its velocity is maximum at the mean position and zero on the extreme positions.

In view of these characteristics we can define SHM as:

The acceleration of a body executing SHM is directly proportional to the displacement from the mean position, and always directed towards the mean position.

Example 12.1: Find the time periods of a simple pendulum of 1 metre length, placed on Earth and on moon. The value of g on the moon is $1/6$ of its value on Earth. Where $g = 10 \text{ ms}^{-2}$

Solution: The time period of a simple pendulum on Earth is given by:

$$T_E = 2\pi \sqrt{\frac{\ell}{g}}$$

By substituting the values

$$T_E = 2 \times 3.14 \sqrt{\frac{1 \text{ m}}{10 \text{ ms}^{-2}}} = 2 \text{ s}$$

The time period of the same pendulum on moon is given by:

$$T_m = 2\pi \sqrt{\frac{\ell}{g/6}} = 2\pi \sqrt{\frac{6\ell}{g}}$$

By substituting the values

$$T_m = 2 \times 3.14 \sqrt{\frac{6 \times 1 \text{ m}}{10 \text{ ms}^{-2}}} = 4.9 \text{ s}$$

Example 12.2: A body of mass 0.5 kg is attached to a spring placed on a horizontal frictionless surface. If the spring constant of this spring is 8 Nm^{-1} , find the time period of the body.

Solution:

$$m = 0.5 \text{ kg} \quad , \quad k = 8 \text{ Nm}^{-1} \quad , \quad T = ?$$

As we know that $T = 2\pi \sqrt{\frac{m}{k}}$

By putting the values $T = 2\pi \sqrt{\frac{0.5 \text{ kg}}{8 \text{ Nm}^{-1}}} = 1.57 \text{ s}$

12.3 WAVES AND THEIR TYPES

We have already seen that waves are produced in a medium due to such a disturbance which causes the particles of the medium to exhibit simple harmonic motion about their mean position one by one after a particular intervals of time. In this way this disturbance is transmitted from one part of the medium to the other in the form of waves. We have already discussed two examples of waves earlier. One was the waves produced on the surface of water and the other one was that of the waves produced in a stretched string. In both examples, waves need a medium for their production and propagation. In these examples, water and string serve as a medium. Such waves are called "Mechanical Waves".

There are such waves which do not require a medium for their propagation. Such waves are called "Electromagnetic Waves". Radio waves, television waves, x-rays, heat and light waves are the examples of such waves.

We will further discuss the mechanical waves in this chapter. Mechanical waves are of two types:

- (i) Transverse waves,
- (ii) Compressional or longitudinal waves.

Transverse Waves

The waves produced on the surface of water have been briefly examined in the experiment given at the beginning of this chapter. You have seen that if one end of the pencil is dipped in the water and then moved up and down, waves are produced on the surface of water, and due to the passage of these waves, the particles of water vibrate up and down. This means that the direction of vibratory motion of the water particles is perpendicular to the motion of the waves. Such waves are known as transverse waves. The waves produced by moving one end of a stretched

string up and down are also transverse waves, because different parts of the string vibrate perpendicular to the string. Therefore, transverse waves can be defined as:

Transverse waves are such waves in which the particles of the medium vibrate perpendicular to the direction of propagation of the wave.

A sketch of the transverse waves is given in Fig. 12.5, which shows that when transverse waves pass through a medium, some of its particles move upward while at the same instant some of them move downward. Those parts of the transverse waves where the particles of the medium are above the normal position are called 'crest' and parts where the particles of the medium are below their normal position are called 'trough'.

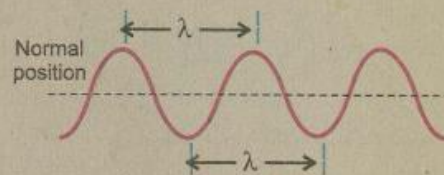


Fig 12.5

The distance between two consecutive crests or troughs is called wavelength represented by Greek letter λ . A crest and a trough combined together to make one complete wave. The number of waves passing through a point in one second is called the frequency of the wave. The unit of frequency is 'hertz'. The relation between frequency f and time period T is given as:

$$f = \frac{1}{T} \quad \dots\dots\dots (12.6)$$

Compressional or Longitudinal Waves

The type of waves in which the direction of the vibratory motion of the particles of medium is parallel to the direction of propagation of wave, are called compressional or longitudinal waves. We will study in the next chapter about the sound waves in air which are longitudinal waves.

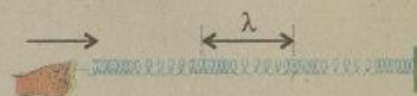


Fig 12.6

12.4 WAVES AS CARRIERS OF ENERGY

There are two methods of transferring energy from one place to another:

- (i) through matter and (ii) through waves

Most of the time, energy is carried by matter. For example, when gun is fired, the bullet gets energy through explosion and moves towards the target. The energy of the bullet is kinetic energy. On striking the target, it transfers its K.E. to it. The energy of running water in the tunnel of a dam is also kinetic in nature. On reaching the turbine, it transfers its energy to the blades of the turbine due to which it starts rotating and produces electricity.

From above examples we come to conclusion that energy

Do you know?



Sometimes the huge energy of the oceanic waves causes the destruction of ships and coastal areas.

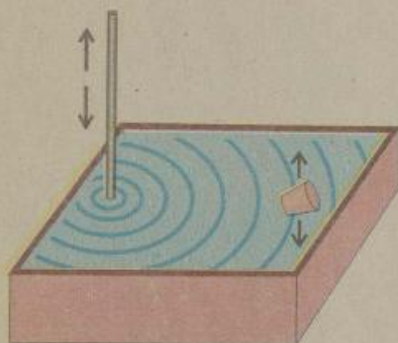


Fig. 12.7

can be transferred through matter. However, matter is also displaced during this mode of energy transfer. Energy can also be transferred by wave phenomenon without transfer of matter. This can be proved by a simple experiment.

Experiment: Fill a big rectangular tray with water and start up-down motion of one end of a vertical rod after dipping it in the water (Fig. 12.7). Transverse waves will be produced on the surface of water moving away from the position of rod. Place a cork on the surface of water near the other end of the tray opposite to rod. When waves pass through this cork, the cork vibrates up and down perpendicular to water surface at its place. We impart energy in moving the rod up and down. This energy reaches the cork through water waves due to which cork vibrates. Remember that when the waves are moving the water particles do not make any forward motion along the direction of waves; they keep on vibrating at their respective places as wave passes through it. The light and heat reaches us from Sun through waves.

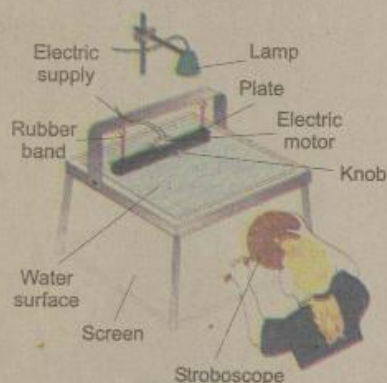


Fig. 12.8

12.5 PROPERTIES OF WAVES

Now we take an over view of certain properties (e.g., reflection, refraction, interference, diffraction etc.) of waves. The simple apparatus, called ripple tank is used for this purpose. The construction and use of ripple tank is being given below:

Ripple Tank

This apparatus consists of a rectangular tray with glass bottom and is placed nearly half metre above the surface of a table by means of four supporting legs. Waves are produced on the surface of water present in the tray by means of a vibrator. This vibrator is an oscillating electric motor which is fixed on a wooden plate. This plate is suspended by means of rubber bands and its lower end touches the water surface. On setting vibrator on, this plate starts vibrating and straight waves are generated on the water surface (Fig. 12.8). An electric bulb is hung over the tray. With the help of its light, the image of water waves is obtained on the white paper or screen. The crests of the waves appear as bright lines on the paper because they function like convex lens and converge the rays of light falling on them. On the other hand, troughs behave like concave lenses and diverge the light, thereby appearing as dark straight portions between bright lines.

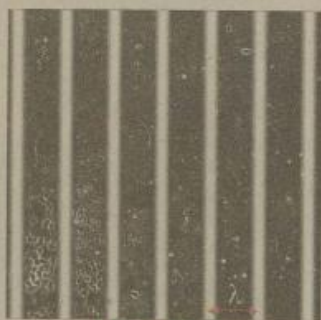


Fig. 12.9



Fig. 12.10

To generate circular waves, the vibrating bar is raised up and a knob attached to it is lowered in such a way that it touches the water surface. When vibrator is set on, circular waves are produced on the water surface (Fig. 12.10). Remember that Fig. 12.10 is a snapshot of such waves taken by a very high power camera, these waves are actually seen moving on the paper. For

the detailed analysis of these moving waves, they should be "frozen" by one way or the other. This is done by means of a device called stroboscope. A simple stroboscope has been shown in Fig 12.11. It consists of a round disc with slits on its edge. This disc can be rotated about its centre by putting it into motion by a finger. When we see through this disc, we see waves only when a slit passes against our eye. If we adjust the speed of stroboscope, so that a slit in front of our eye is replaced by another during the time in which the waves move forward by one wavelength, the waves appear to be stationary and we say that their motion is rather "frozen".

Relation Between Velocity, Frequency and Wavelength

We can find easily the wavelength (λ) of a wave, which is the distance between two adjacent crests or troughs. On the screen below the tray of ripple tank we can see waves in motion for which the distance between two successive crests remains constant and can be measured easily.

If we place a piece of paper on the water surface and observe its motion, we find that it vibrates up and down on its place and do not move forward in the direction of motion of the wave. We also note that time of one vibration of the paper is equal to the time taken by two adjacent crests (or troughs) to pass through a certain point. As the distance between two adjacent crests or troughs is equal to one wavelength, therefore during the time of vibration of a piece of paper the wave covers a distance equals to one wavelength. Moreover, if we measure the time of one vibration of a piece of paper and time period of the plate, then we will observe that both are equal. So, if the speed of the wave is v and the time period of the plate, producing waves is ' T ' second, then the distance covered by the wave will be vT . As it is equal to the wavelength, therefore

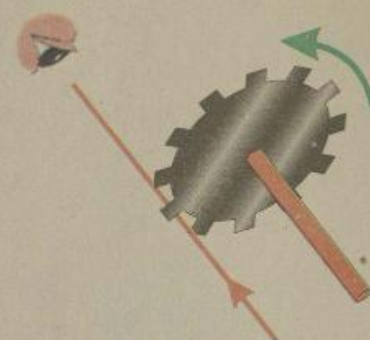
$$\lambda = vT \quad \dots\dots\dots (12.7)$$

or
$$v = \frac{\lambda}{T} = \lambda \times \frac{1}{T}$$

If we use Eq.(12.6), above equation can be written as,

$$v = f\lambda \quad \dots\dots\dots (12.8)$$

Eq. (12.8) shows that wave speed is the product of frequency and wavelength. Frequency of waves, that is number of waves passing through certain point in one second, can be changed by changing frequency of vibrator. Other two quantities (i.e., v and λ) depend upon the properties of the medium.



Stroboscope
Fig 12.11

Example 12.3: The wavelength of a wave passing through a medium is 0.1 metre. If wave speed is 2ms, then calculate the wave frequency.

Solution:

$$\lambda = 0.1 \text{ m} \quad , \quad v = 2 \text{ ms} \quad , \quad f = ?$$

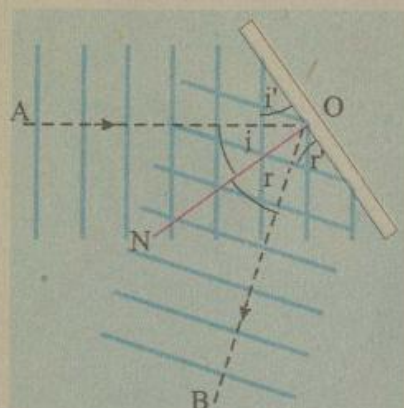


Fig. 12.12 (a)



Fig. 12.12 (b)

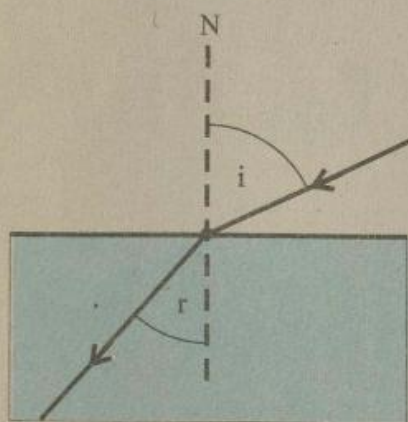


Fig. 12.13

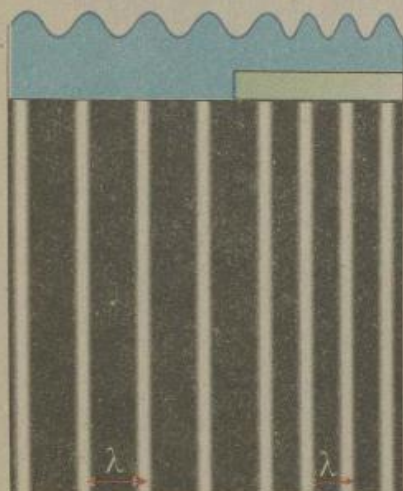


Fig 12.14 (a)

As

$$v = f\lambda$$

So

$$f = \frac{v}{\lambda} = \frac{2\text{ms}^{-1}}{0.1\text{m}} = 20\text{Hz}$$

Using ripple tank we will discuss four important properties of waves.

Reflection

The travelling water waves are reflected according to the laws of reflection of light waves. To observe the reflection of water waves, straight waves are generated in the ripple tank. Place a plane surface obstacle in the path of waves making certain angle with the direction of propagation of waves. After striking the obstacle, the waves will be reflected in a particular direction (Fig. 12.12-a). By using stroboscope and protractor measure the angle $\angle i'$ between the incident ray and plane obstacle. Similarly the $\angle r'$ between the reflected ray and plane obstacle is also measured. We will find that these two angles are equal i.e., $\angle i' = \angle r'$. In Fig 12.12 (a), the line AO drawn perpendicular to the incident waves represents the direction of propagation of incident waves. The angle between the line AO and normal NO to the plane hurdle gives the angle of incidence $\angle i$. Similarly, the line OB drawn perpendicular to the direction of propagation of reflected waves shows the direction of propagation of reflected waves and the angle between ON and OB is the angle of reflection $\angle r$. We know that angle between two line segments is equal to the angle between their respective normals. So $\angle i' = \angle i$ and $\angle r' = \angle r$. According to the measurement $\angle i' = \angle r'$, Therefore $\angle i = \angle r$.

Thus we can say, the law of reflection of water waves is identical to the law of reflection of light.

Refraction

When a ray of light enters from one transparent medium to another transparent medium, it bends from its path (Fig. 12.13). This bending of waves from their incident path is called "Refraction". The refraction occurs due to the change in speed of light in the other medium. Remember that speed of light is more in air (or vacuum) than in glass or water.

Like light, water waves exhibit the phenomenon of refraction. The speed of water waves depends upon the depth of water. Its speed is reduced when it enters in shallow water.

To observe the relation between wave speed with water depth, we cover half of the bottom of the ripple tank with a thick glass plate. In this way we get two portions of water with different depths. Remember that the edge of the plate separating these two portions should be parallel to the bar of the vibrator. When the electric motor is put on, straight waves are produced on the water

surface (Fig. 12.14-a). You can see in this figure that the wavelength of the waves decreases when they reach the shallow part. The frequency of the waves remains the same in both parts of the water because it is equal to the frequency of the vibrator. In the shallow part according to the equation $v = f \lambda$ the decrease in wavelength is due to decrease in the speed of the waves.

For observing the refraction of water waves, we repeat this experiment in such a way that in a ripple tank the line separating two different parts of depths makes an angle with the waves. Now you will see that in addition to the change in wavelength the waves change the direction of propagation also. As they cross the line separating the two sections of different depths (Fig. 12.14-b). In this figure we can observe that when water wave enters the shallow part they bend towards normal on the line separating the two parts. This changing of path of water waves is called refraction.

Diffraction

Generate the straight waves in a ripple tank and place two obstacles in a line in such a way, that separation between them is equal to the wavelength of water wave. After passing through the slit between two obstacles, the waves can be noted spreading in every direction and changing to circular form (Fig 12.15-a). This bending of waves around the corners or obstacles is called "Diffraction".

Diffraction of waves can only be observed clearly if the size of the slit or obstacle is nearly equal to the wavelength of the wave. Fig. 12.15 (b) shows a wave passing through a slit with size larger than the wavelength of the wave. Here the diffraction is not significant and waves keep their initial motion even after passing through the slit and their shape remain straight. However, a little diffraction effect appears near the corners of the obstacle.

Interference

We have discussed how particles of the medium get displaced from their equilibrium position when a wave passes across it. Now we will see that when particles of a medium are subjected to two waves simultaneously an interesting phenomenon known as interference, takes place.

If two identical waves propagate through a medium in such a way that crest of one wave falls on the crest of the other and trough of the one falls on the trough of the other, then the resultant displacements of particles when the two waves simultaneously act upon them get double the displacement of the individual wave. Such an interference has been shown in Fig. 12.16 (a). In this figure one wave has been shown by dotted line while the other with solid line and they are shown to be helping each other and generating a

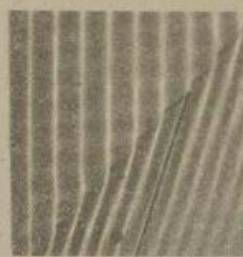


Fig. 12.14 (b)

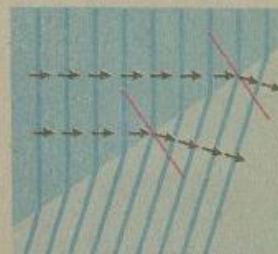


Fig. 12.14 (c)

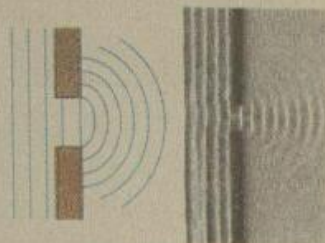


Fig. 12.15 (a)

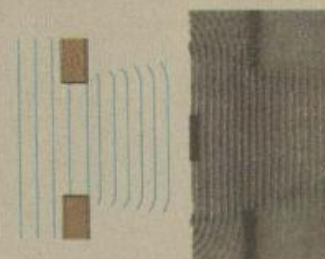


Fig. 12.15 (b)

Interesting information



Due to diffraction of radio waves, transmission can be heard in such areas where the waves cannot reach directly.

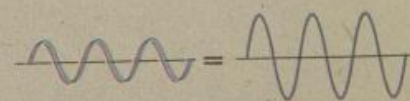


Fig. 12.16 (a)

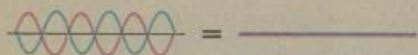


Fig. 12.16 (b)



Fig. 12.17 (a)

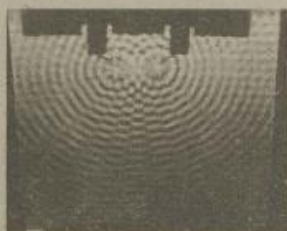


Fig. 12.17 (b)

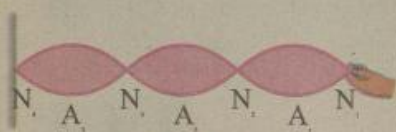


Fig. 12.18



Fig. 12.19

single wave of double the amplitude. Such an interference is called constructive interference.

On the other hand, if two identical waves act upon the particles of the medium in such a way, that the crest of the one falls on the trough of the other, they cancel the effect of each other and as a result the surface of the medium remains undisturbed. Such an interference is called destructive interference (Fig. 12.16-b).

To observe interference of water waves, the two knobs attached to the vibrating bar of the vibrator are lowered so that they touch the water surface. When the motor is switched on, two sets of circular waves are seen to be moving on the water surface. The frequency and amplitude of two waves is same and these are generated at the same time. On the surface of water where these sets of waves pass simultaneously, interference occurs and can be seen (Fig. 12.17-b).

12.6 STATIONARY WAVES

Fasten one end of a string to a firm support and hold its other free end by your hand. The up and down motion of the hand will produce waves in the string. If we keep on increasing the rate of up and down motion of hand, then at a particularly frequency, the string will start vibrating making a shape, like the one shown in Fig. 12.18. Such waves are called stationary waves. Due to such waves, the amplitude of the string on different sections of the string is different. At some portions of the string the amplitude is zero while it is maximum on others. The former points like N, N, ... where amplitude is zero are called nodes while others like A, A, ... where amplitude is maximum are called antinodes. The wavelength of the stationary wave is twice the distance between two successive nodes or antinodes.

The number of loops on the string depend upon the frequency of up and down motion of the hand. The string makes a single loop at the lowest frequency. This frequency is called fundamental frequency or first harmonic. If the string makes two loops, the frequency at which it does so is called second harmonic or first overtone and this frequency is found to be two times the fundamental frequency. Even at higher frequencies, the string can be seen making three, four loops representing third, fourth harmonics. In Fig 12.19, third harmonic of a string has been shown.

To generate stationary waves, two exactly identical waves in all respects travelling in the opposite direction along the same line are necessarily required. In above mentioned experiments stationary waves are produced due to interference of a wave being generated by the up and down motion of the hand and the one (exactly identical) being reflected by the support and travelling in the opposite direction on the string.

Example 12.4: A stationary wave of fundamental frequency 250 Hz has been generated in a medium. Calculate three higher frequencies by using formula $f_n = nf_1$, at which stationary waves could be produced.

Solution:

Fundamental frequency $= f_1 = 250 \text{ Hz}$

Therefore, three higher frequencies at which stationary waves could be generated are $2f_1$, $3f_1$, $4f_1$. So,

$$f_2 = 2f_1 = 500 \text{ Hz}$$

$$f_3 = 3f_1 = 750 \text{ Hz}$$

$$f_4 = 4f_1 = 1000 \text{ Hz}$$

SUMMARY

1. Simple harmonic motion (SHM) is a kind of vibratory motion in which acceleration of the body is directly proportional to the displacement from equilibrium position and always directed towards the equilibrium position.
2. The motion of mass attached to a spring and that of simple pendulum is SHM.
3. The kind of waves which require a medium for its propagation are called mechanical waves.
4. Transverse waves are the kind of mechanical waves in which particles of the medium vibrate about their mean position perpendicular to the direction of propagation of the waves.
5. Compressional waves are those mechanical waves in which particles of the medium vibrate about the equilibrium position in the direction of propagation of the waves.
6. Wave is a source of transferring energy from one place to another.
7. The wave speed (v) of a wave is equal to the product of frequency (f) and wavelength (λ) i.e., $v = f\lambda$.
8. When waves enter from one medium to another, a part of it is reflected in the same medium while the other part is transmitted into the other medium. This phenomenon is called refraction of waves. The wave speed and wavelength of wave change in the second medium but frequency does not change.
9. The bending of waves around obstacles is called diffraction.
10. When particles of medium are subjected to two or more than two waves simultaneously, then effect being produced is called interference.
11. When two identical waves pass through a medium along the same line in opposite directions, then stationary waves are produced at certain frequencies.

QUESTIONS

12.1 Define vibratory motion. Give conditions of a vibratory motion.

12.2 Define simple harmonic motion and prove that vibrating motion of mass

attached to spring is SHM.

12.3 Define the following terms: Displacement, amplitude, frequency, time period. Describe simple pendulum

as an example of SHM.

12.4 What is a wave? Describe its types and define them.

12.5 Describe transverse and longitudinal waves as kinds of mechanical waves.

12.6 Using ripple tank establish a relation between wave speed (v), frequency (f) and wavelength (λ).

12.7 Using ripple tank explain the following characteristics of a wave: Reflection, refraction, interference and diffraction.

12.8 Describe briefly that how are stationary waves generated?

12.9 Explain the formation of nodes and antinodes in stationary waves.

12.10 Fill in the blanks.

- (i) The restoring force is numerically equal to _____ but opposite in direction.
- (ii) There is _____ relation between frequency and time period.
- (iii) Waves carry _____ from one place to another.
- (iv) The distance between two successive crests is _____.
- (v) The bending of waves around the corners is called _____.

12.11 Tick ($\checkmark$) the correct answer.

- (i) The maximum potential energy of a vibrating mass attached to a spring is at
 - (a) equilibrium position
 - (b) extreme position
 - (c) between equilibrium and extreme positions
 - (d) all of them.

(ii) The product of frequency and time period is equal to:

- (a) v (b) 1 (c) 0 (d) λ

(iii) If the mass of bob of a simple pendulum is doubled, its time period

- (a) is doubled
(b) becomes four times
(c) remains the same
(d) none of the above.

(iv) If the length of a simple pendulum is halved, its time period T will become

- (a) $\frac{T}{2}$ (b) $\frac{T}{\sqrt{2}}$
(c) $\sqrt{2}T$ (d) $2T$

(v) In terms of wavelength (λ), the distance between two neighbouring nodes and antinodes is

- (a) λ (b) $\frac{\lambda}{2}$
(c) $\frac{\lambda}{4}$ (d) 2λ

12.12 Mark (T) for true and (F) for false.

- (i) Simple harmonic motion is a kind of circular motion. (T/F)
- (ii) In a mass spring system, simple harmonic motion could occur within Hooke's law limits. (T/F)
- (iii) Restoring force is not always needed for simple harmonic motion. (T/F)
- (iv) Time period of a simple pendulum also depends upon the acceleration due to gravity. (T/F)
- (v) When a wave enters from one medium to another, its frequency changes. (T/F)

NUMERICAL PROBLEMS

- 12.1** The time period of a simple pendulum is 2s. What will be its length on Earth? What will be its length on moon if

$$g_m = g/6?$$

(1.02 m, 0.17m)

- 12.2** Length of a spring is 8 cm. When a mass of 4kg is hung to it, its length becomes 16 cm. What is its spring constant?

(500 Nm)

- 12.3** If five waves pass through a point of a medium in 10 seconds. What is its frequency and time period? If its

wavelength is 5 cm, calculate the wave speed.

(0.5 Hz, 2s, 25mms)

- 12.4** The time period of a wave is 5s. If velocity of the wave is 10ms, then what will be its wavelength?

(50m)

- 12.5** A stationary wave is making five loops. The distance between two stationary points is 10 cm and its velocity is 20 ms. What will be its frequency? What will be the fundamental harmonic frequency?

(100 Hz, 20 Hz)

SOUND

In this chapter you will learn:

1. How is sound produced?
2. Nature and propagation of sound.
3. Detection of sound.
4. Characteristics of sound.
5. Speed of sound.
6. Audible frequency range.
7. Use and characteristics of Ultrasonic.



Musical sound is produced from guitar.

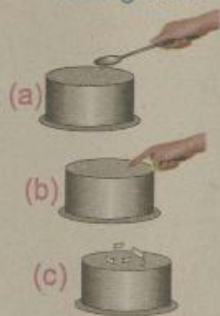


Fig. 13.1

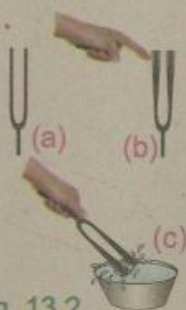


Fig. 13.2

We hear many types of sound in our daily life. Apart from our normal talks some are just audible such as whispering of friends or rustling of leaves while other are very loud such as sound of pressure horns of buses or that of shouting of children. Some sounds are pleasant to our ear while other produce jarring effect such as barking of dogs, the rattling sound of a tractor. How are these different sounds produced? How does sound propagate? How do we hear sound? What are the characteristics of musical sound? All these questions will be answered in this chapter. Moreover modern topics such as ultrasonic and different methods of finding the speed of sound will also be discussed.

13.1 HOW IS SOUND PRODUCED?

Sound, in fact, is a form of energy and it is produced by a vibrating body. Whenever a sound is produced, the vibrations of the sounding body can be observed or felt.

Place a pan upside down on a table and strike it with your finger (Fig. 13.1-b), a particular sound will be heard. You can feel its vibrations by touching it with your finger. You can also see the vibrations of the pan by placing small pieces of paper on it, (Fig. 13.1-c) which start vibrating.

In school laboratory a device called a tuning fork is used for producing a particular sound (Fig. 13.2-a). It is U-shaped having two metal prongs with a stem at the bottom. If we strike a tuning fork on a rubber pad, a sound is heard and the prongs of the tuning fork start vibrating. The vibrations of the tuning fork can be felt by touching its prongs with your finger (Fig. 13.2-b). If you put the ends of the prongs in water after striking the tuning fork, you will see a splash (Fig. 13.2-c). What makes the water splash?

We can conclude from the above observations that sound is produced by vibrating bodies. In other words, we can say that a body can produce a sound only when it is vibrating.

13.2 NATURE AND PROPAGATION OF SOUND

We have seen that all sounds are produced by vibrating bodies. During its vibratory motion, a vibrating body moves to and fro around its rest position and produces compressional waves in the surrounding air. These compressional waves are called the sound waves which travel from one place to the other. We can get more information about the production and propagation of sound by considering in detail the motion of the vibrating tuning fork.

A specific sound is produced by striking a tuning fork on a rubber pad. The prongs of such a tuning fork begin to vibrate. A vibrating tuning fork is shown in Fig. 13.3. Its right hand prong vibrates about its rest position 'O' between two points 'A' and 'B'. When the prong moves from 'A' to 'B', it compresses the layer of air in front of it. The compressed layer transfers its increased pressure to the air layer next to it. This process continues and the compression produced by rightward movement of the prong, moves outwards. On reaching the point 'B' the prong begins to move towards the point 'A'. During such a motion of the prong pressure in the adjacent air layer decreases and a rarefaction is produced here. The first layer, where a rarefaction has been produced, transfers its decrease in pressure to the next layer and after doing so it comes to its normal state. This process also continues and the rarefaction produced in the first layer moves outwards. As the tuning fork continues to vibrate, compressions and rarefactions are produced and travel outwards one after the other. Such a series of compressions and rarefactions are the sound waves. As the molecules of air move in the direction of waves during their vibratory motion, we can conclude that sound waves are compressional waves.

We have seen that sound waves can travel through air. Sound waves can also travel through gases, liquids and solids. Now we perform some experiments which will show that a material medium is necessary for the sound waves to travel from the vibrating body to our ears.

Experiment 13.1

Arrange the apparatus as shown in Fig. 13.4, where a bell jar is placed on the platform of a vacuum pump. An electric bell is suspended with the help of two wires passing through a cork fixed in the mouth of the bell jar. The electric bell will begin to ring on connecting the free ends of the two wires to a battery. The sound of the bell can be heard. Now start pumping out air from the jar by means of vacuum pump. The sound of the bell becomes less pronounced. At last the sound of the bell becomes hardly audible in spite of the fact that we see the hammer striking the bell. When we let air into the jar we can hear the sound of the bell again. We can conclude from this experiment that the presence of air is necessary for the propagation of sound.



Fig. 13.3



Fig. 13.4



Fig. 13.5

Experiment 13.2

Ring the bell inside the water near the bank of a pond. At some distance from the bell, suspend the stethoscope in water such that its detector is directed towards the bell (Fig. 13.5). The sound of the bell can be clearly heard through the stethoscope. We can infer from this experiment that sound can travel easily even through water.

Experiment 13.3

Strike one end of long railing with a hammer (Fig.13.6). Your friend standing near the other end of the railing, can hear the sound on bringing his ear near the railing. If the railing is very long, your friend hears two sounds, one through the railing and a moment later a second one through air. This shows that the speed of sound in solid is greater than in air.

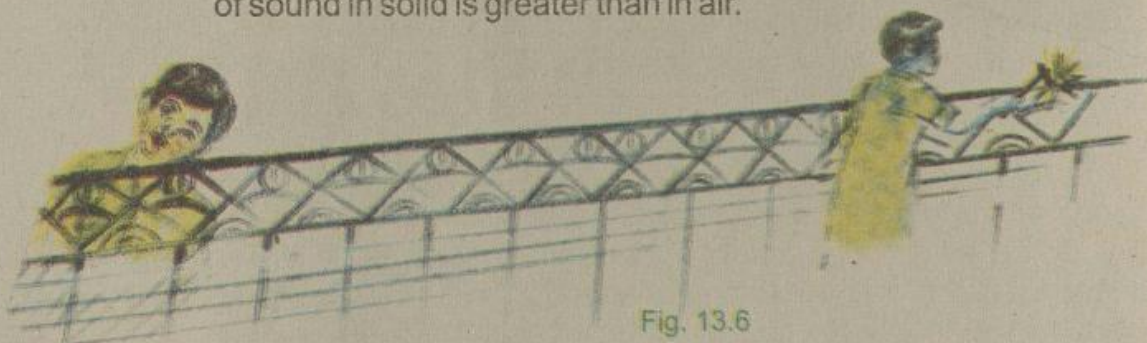


Fig. 13.6

We conclude from the above experiments that a material medium is necessary for the propagation of sound from one place to another. This material medium may be a gas, a liquid or a solid.

13.3 HEARING OF SOUND

We can hear sound by our ear which is a very delicate organ of our body. It has three parts:

- | | | |
|---------------|-----------------|-----------------|
| (i) Outer ear | (ii) Middle ear | (iii) Inner ear |
|---------------|-----------------|-----------------|

The horn-like part of the ear which can be seen from outside is called the outer ear. Near its centre there is an open canal which terminates at a diaphragm called the eardrum. The external ear collects the sound waves and directs them to the eardrum. When the sound waves reach the eardrum, they make it to vibrate. The eardrum separates the outer ear from the middle ear. The middle ear is a small, irregular cavity. The wall of the middle ear opposite the eardrum, which separates the middle ear from the inner ear, has a small opening called the oval window. Stretching across the middle ear, from the eardrum to the oval window there are three tiny, movable bones which are named as hammer, anvil and stirrup. When the sound waves reach the eardrum, it starts vibrating. The feeble vibrations of the eardrum are conveyed to the inner ear through the chain of these bones and the oval window.

The structure of the inner ear is quite complicated but its part which plays an important part in the hearing process is called cochlea. It is shaped like a small snail and is filled with a jelly-like fluid. There are countless hair like structures in cochlea which are in fact the endings of the fibres of the auditory nerve, connected to the brain. The vibrations produced by the sound waves reach the inner ear through the oval window and the pressure of the liquid in it changes accordingly. As the hair-like parts in the cochlea respond to different frequencies of vibrations, they stimulate the different fibres of the auditory nerve which enters into the cochlea from the brain and start sending impulses to the brain where these messages are interpreted as the feeling of sound.

13.4 CHARACTERISTICS OF SOUND

Some characteristics of musical sound are given below.

(i) Loudness of Sound

It is such a characteristic of sound by which a loud and a faint sound can be distinguished. When we talk to our friends, our voice is low, but when we address a public gathering our voice is loud. Loudness of a sound depends upon many factors. Some of them are discussed below:

(a) Amplitude of Vibrating Body

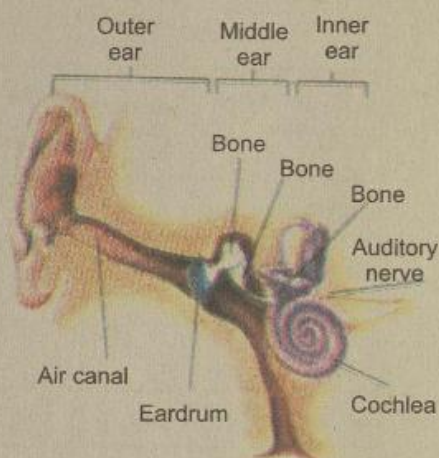
If the amplitude of the vibrating body is large, the sound produced will be loud, while the sound will be low if the amplitude is small. That is the reason why the sound produced by sitar is loud if its wires are plucked violently. Similarly when we beat a drum forcefully, its membrane vibrates with a large amplitude and a loud sound is produced. Thus the loudness increases with amplitude of the vibrating body.

(b) Area of Vibrating Body

It is quite evident that larger the area of the surface of the vibrating body, louder is the sound produced by it. If we strike a tuning fork on a rubber pad, it begins to vibrate and a feeble sound is heard. If the same vibrating tuning fork is placed vertically on a table, the sound becomes louder. It is because the table top also begins to vibrate along with the tuning fork and the total vibrating area increases. Similarly the sound produced by a large drum is louder than that by a small one because of its large vibrating area.

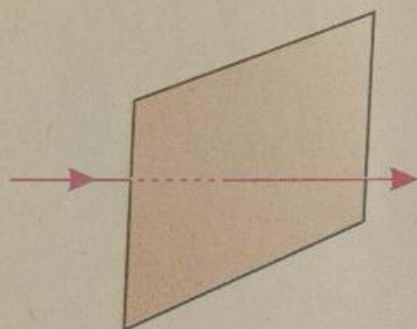
(c) Distance from Vibrating Body

Loudness of a sound also depends upon the distance of the vibrating body from the listener. Loudness of a sound also depends on the physical condition of the ears of the listener. A sound appears louder to a person with sensitive ears than to a man with defective ears. On the other hand sound has a characteristic which does not depend upon the condition of the ear and it is called the intensity of the sound which will be discussed below:



(Human ear)

Fig. 13.7



Direction of sound
Fig. 13.8

(ii) Intensity of Sound

We know that the waves are very effective means of transporting energy from one place to another. We also know that sound waves are compressional waves. Thus we can say that energy flows from the sounding body to the listener.

Sound energy flowing per second through a unit area held perpendicular to the direction of sound waves is called the intensity of sound (Fig. 13.8)

The unit of intensity of sound is watt per square metre. It is clear from the definition of intensity that it is a physical quantity and it can be measured accurately. The intensities of some of the sound are given in table 13.1. This table shows that the intensity of faintest audible sound is 10^{-12} Wm^{-2} and the intensity of loudest sound, which can be heard without pain is 1 Wm^{-2} . Thus

Table 13.1

Type of sound	Intensity (Wm^{-2})	Intensity level (decibel)
Loudest sound which can be heard without pain i.e. (Threshold of pain)	1	120
Sound of train	10^{-2}	100
Heavy street traffic	10^{-3}	90
Ordinary conversation	10^{-6}	60
Average whisper	10^{-10}	20
Rustle of leaves	10^{-11}	10
Faintest audible sound i.e., Threshold of hearing	10^{-12}	0

It may be remembered that intensity of sound is a physical quantity and it does not depend on the condition or sensitiveness of the ear whereas the magnitude of the sensation produced on the ear by a sound is called its loudness. The loudness of a sound depends not only the intensity of sound but also on the physical condition of the ear.

It has been proved experimentally that for human ear loudness (L) of a sound is not directly proportional to its intensity I , but it is proportional to the logarithm of intensity i.e.,

$$L \propto \log I$$

$$L = K \log I \quad \dots\dots\dots (13.1)$$

Eq. 13.1 is mathematical representation of Weber Fechner law and K is the constant of proportionality.

If L_1 represents the loudness of the faintest audible sound of intensity I_1 and L is the loudness of an unknown sound of intensity I then by Eq. 13.1 we can write

$$L_1 = K \log I_1 \quad \dots\dots\dots (13.2)$$

Subtracting Eq. 13.2 from Eq. 13.1 we get,

$$L - L_1 = K (\log I - \log I_1) = K \log \frac{I}{I_1}$$

The difference between the loudness of these two sounds ($L - L_1$) is called the intensity level or sound level of the unknown sound. Therefore the intensity level of an unknown sound is given by

$$\text{Sound level} = K \log \frac{I}{I_1} \quad \dots\dots\dots (13.3)$$

The value of K depends not only on the units of I and I_0 but also on the unit of intensity level. If the intensity I of any unknown sound is 10 times greater than the intensity I_0 of the faintest audible sound i.e., $I = 10I_0$ and the intensity level of such a sound is taken as unit, called bel, the value of K becomes 1. Substituting $K = 1$, Eq 13.3 becomes

$$\text{Sound level} = \log \frac{I}{I_0} \text{ (bels)} \quad \dots\dots\dots (13.4)$$

Bel, the unit of intensity level of a sound is very large. Generally a smaller unit called **decibel** is used. Decibel is abbreviated as (dB). It must be remembered that 1 bel is equal to 10dB. If the intensity level is measured in decibels, Eq. 13.4 can be written as

$$\text{Sound level} = 10 \log \frac{I}{I_0} \text{ (dB)} \quad \dots\dots\dots (13.5)$$

Using Eq.13.5 we can construct a scale for measuring the intensity level of sound. Such scale is known as "decibel scale". For better understanding of decibel scale we calculate the intensity level of different sounds.

Intensity level of faintest audible sound can be calculated by substituting $I = I_0 = 10^{-12} \text{ Wm}^{-2}$ in Eq.13.5 Thus

$$\text{Intensity level of faintest audible sound} = 10 \log \frac{I}{I_0} = 10 \log \frac{I_0}{I_0} = 0 \text{ dB}$$

As the intensity of rustle of leaves is $I = 10^{-11} \text{ Wm}^{-2}$, therefore

$$\text{Intensity level of rustle of leaves} = 10 \log \frac{10^{-11}}{10^{-12}} = 10 \log 10 = 10 \text{ dB}$$

For whispering, $I = 10^{-10} \text{ Wm}^{-2}$, hence

$$\text{Intensity level of whispering} = 10 \log \frac{10^{-10}}{10^{-12}} = 10 \log 100 = 20 \text{ dB}$$

The above mentioned examples help us to construct the decibel scale for finding the intensity level of different sounds which is given in table 13.2.

Table 13.2: decibel scale

Intensity of sound W m^{-2}	Relative intensity of sound $\frac{I}{I_0}$	Sound level dB
10^{-12}	10^0	0
10^{-11}	10^1	10
10^{-10}	10^2	20
10^{-9}	10^3	30
10^{-8}	10^4	40
10^{-7}	10^5	50
10^{-6}	10^6	60
10^{-5}	10^7	70
10^{-4}	10^8	80
10^{-3}	10^9	90
10^{-2}	10^{10}	100
10^{-1}	10^{11}	110
10^0	10^{12}	120
10^1	10^{13}	130

(iii) Pitch of Sound

The characteristic of sound by which a shrill sound can be distinguished from a grave one is called the pitch of the sound. It depends upon the frequency, the greater the frequency, the higher the pitch and lower the frequency, the lower the pitch. The frequency of the voice of ladies and children is greater than that of men. Therefore, the voice of ladies and children is shrill and of high pitch.

The dependence of pitch on the frequency of sound can be studied by a simple experiment given below. Support a bicycle on

its stand and rotate its rear wheel. Hold a piece of cardboard in your hand with its free end touching the spokes of the rotating wheel. The cardboard will begin to vibrate and a sound will be heard. Now start increasing the speed of the rotation of the wheel. The vibrations of the cardboard will become quicker and its frequency will start to increase. The sound produced will become shriller.

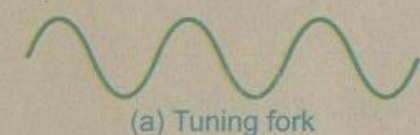
(iv) Quality of Sound

The characteristic of sound by which two sounds of same loudness and pitch are distinguished from each other is called the quality of sound. If in a room, a note of given loudness and pitch is sounded on a flute and also on a piano, one can easily distinguish between them even from outside the room because the quality of these notes is different.

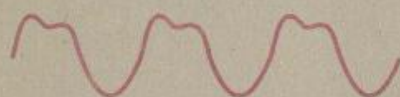
Fig. 13.9 shows the wave form of the sound produced by a tuning fork and that produced by a piano. The loudness and pitch of these two sounds are the same but their waveforms are different. So their quality is different and they can be distinguished from each other.

(v) Noise and Music

While enjoying the programs of radio or television we hear different sounds. In musical programs we hear pleasant sounds produced by musical instruments such as flute, harmonium, violin, drum etc. Such sounds which have pleasing effect on our ears are called musical sounds. In some dramas we hear sounds which have an unpleasant effect on our ear such as rattling sound of buses or the sound produced by hammering in factories. Sound which has a jarring effect on our ears is called noise. The frequency and amplitude of the musical sound change in a regular manner while the changes in frequency and amplitude of noise are sudden and irregular.



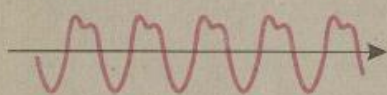
(a) Tuning fork



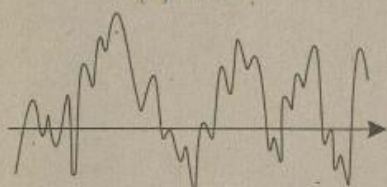
(b) Piano

Fig. 13.9

Interesting information



(a) Music



(b) Noise

Waveforms of music and noise

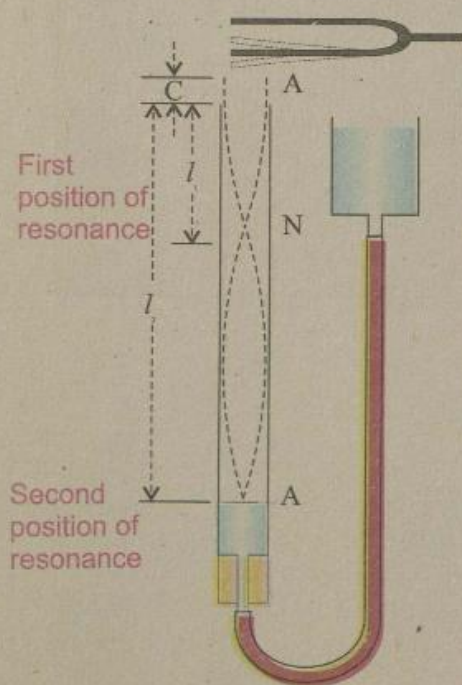


Fig. 13.10

13.5 SPEED OF SOUND

There are many methods of finding the speed of sound. The one described below can be performed in a school laboratory. For understanding this method consider Fig. 13.10 where a column of air is shown enclosed in a vertical glass tube. The tube is connected to a water reservoir. By moving the reservoir up and down the length of the air column can be changed.

Hold a vibrating tuning fork horizontally by over the open end of the glass tube. The tuning fork forces the air column in the tube to vibrate. Starting from a small length of the air column increase its length. For a certain length of the air column the sound of the tuning fork becomes loudest. At this position the air column resonates with the tuning fork frequency. In other words the tuning fork and the air column vibrate with the same frequency. This

phenomenon, in which there is remarkable increase in the amplitude and hence the loudness of the sound when the frequency of air column becomes equal to that of the tuning fork, is called resonance. When a tuning fork vibrates near the edge of the tube, it starts sending the compressional waves. These waves, when strike the water surface, are reflected. These reflected waves and incoming waves produce stationary waves in state of resonance. There will be an antinode at the open end of the tube and a node at the other end. Since the distance between a node and next antinode is equal to one quarter of wavelength, we can write the following equation for the stationary waves, which appears in the vibrating air column.

$$\frac{\lambda}{4} = \ell \quad \text{or} \quad \lambda = 4\ell \quad \dots\dots\dots (13.6)$$

If f is the frequency of the tuning fork, then speed v of the sound can be found by using

$$v = f\lambda$$

Since $\lambda = 4\ell$

Hence, $v = 4f\ell$

where λ is wavelength of the stationary waves and ℓ is the measured length of the air column in the first position of resonance.

13.6 AUDIBLE FREQUENCY RANGE

We know that sound is produced by a vibrating body. A simple pendulum also vibrates but it does not produce any sound. The reason is that its vibrations are very slow. A human ear can hear a sound only if its frequency lies between 20 and 20,000 Hz. In other words a human ear neither hears a sound of frequency less than 20 Hz nor a sound of frequency more than 20,000Hz. Sounds of frequency beyond 20,000 Hz are inaudible because the eardrum can not vibrate so rapidly. The audible frequency range differs a little for different persons. The above mentioned audible frequency range is only an average. It also decreases with age. Young children can hear sounds of 20,000 Hz frequency, but old people can not hear sounds even above 15,000 Hz frequency.

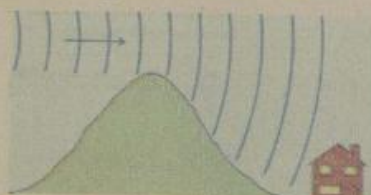
13.7 ULTRASONICS

We know that human ear can not hear sounds of frequency less than 20 Hz or more than about 20,000 Hz. Sounds of frequency higher than 20,000 Hz, which are inaudible to human ear, can be produced and are utilized in many useful ways. Such sounds are called ultrasonics.

Interesting information

Some people use silent whistle to call dogs whose frequency lies between 20,000Hz to 25,000Hz. It is silent for human but not for dogs because their audible frequency range is much more than human.

For your information



The resources of oil and gas beneath the Earth are searched by using ultrasonics.

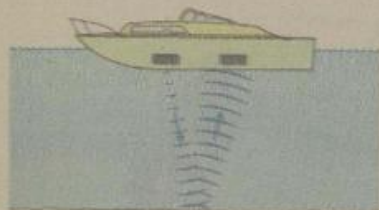
Do you know ?

Ultrasonics waves are used for the scaling of teeth as their vibrations are so intense that they remove easily the dirt and plaque sticking to the teeth.

Interesting information

The kidney stones can be crushed and removed out through urine with the help of ultrasonic waves without any surgery.

Do you know ?



The depth of an ocean is measured by using ultrasonics.

It has been seen that ultrasonic waves carry more energy than audible sound waves. Moreover according to the relation $v = f \lambda$ the wavelength of ultrasonic waves is very small. Due to these characteristics ultrasonics are usefully utilized in medical and technical fields.

In medical field ultrasonic waves are being used to diagnose and treat different ailments. For diagnosis of different diseases ultrasonic waves are made to enter the human body. These waves are reflected differently by different organs, tissues, benign or malignant tumors. The reflected ultrasonic waves are then amplified and fed to a monitor which forms an image of the internal organs of the body on its screen. Such an image helps in detecting the defects of these organs. Now-a-days ultrasonic waves are used not only to find the sex of a baby but also to find its physical abnormalities before birth in the womb of the mother. Powerful ultrasonics are now being used to remove blood clots formed in the arteries.

Due to excessive use cracks appear in the interior of the moving parts of high speed heavy machines such as turbines engines of ships and aeroplanes. These cracks are not visible from outside but they can be very dangerous. Such cracks can be detected by ultrasonics. A powerful beam of ultrasonics is made to pass through these defective parts. While passing these waves are reflected by the surface of these cracks and flaws. The comparison of the ultrasonic waves reflected from the cracks and from the other surfaces of these parts can give a clue of the existence of the cracks.

The depth of an ocean can be measured by using ultrasonics. An ultrasonic pulse is sent down towards the ocean bed from the bottom of a ship. This pulse, after reflection from the ocean bed, reaches the ship where it is detected. The time taken by the ultrasonic pulse in travelling from the ship to the ocean bed and back to the ship is measured. Using this time and the speed of sound in water the depth of the ocean can be determined.

Germs and bacteria in liquids can be destroyed by using high intensity ultrasonic waves.

SUMMARY

1. Sound is produced from a vibrating body which transfers in air from one place to other in the form of compressional waves. A medium is necessary for the travelling of sound.
2. Loudness of sound of a vibrating body depends upon its amplitude, its surface area and distance from the body.
3. Sound energy flowing per second through a unit area held perpendicular to the direction of sound waves is called the intensity of sound.
4. The characteristics of sound by which a shrill sound can be distinguished from a grave one is called the pitch of the sound. It depends upon the frequency.

5. The characteristic of sound by which two sounds of same loudness and pitch are distinguished from each other is called the quality of sound.
6. Such sounds which have jarring effect on our ears are called noise and such sounds which have pleasing effect on

our ears are called musical sounds.

7. Audible frequency range lies between 20Hz to 20,000 Hz.
8. Waves of frequency higher than 20,000 Hz are called ultrasonics which are usefully utilized in medical and other technical fields.

QUESTIONS

- 13.1 How is sound produced? What is its nature?
- 13.2 Prove with the help of simple experiment that a material medium is needed for the propagation of sound.
- 13.3 Write a short note on the detection of sound.
- 13.4 Distinguish between noise and musical sound. Mention the characteristics of musical sound.
- 13.5 Distinguished between loudness and intensity of sound. Define the intensity level of sound. Name and define the unit of intensity level of sound.
- 13.6 Write detailed note on decibel scale.
- 13.7 Explain in detail a laboratory method of measuring the speed of sound.
- 13.8 Write a short note on the following:
- audible frequency range
 - ultrasonics

NUMERICAL PROBLEMS

- 13.1 If the intensity of sound is 1 Wm^{-2} . Calculate its sound level in decibel scale if the intensity of threshold of hearing is 10^{-12} Wm^{-2} .

(120 dB)

- 13.2 The sound of a gun is heard 2 seconds after its flash is seen. Calculate the distance of the gun from the listener. The speed of sound is 340 ms^{-1} .

(680 m)

- 13.3 A vibrating tuning fork of frequency 256Hz is held over the top of a vertical tube full of water. The water is allowed to flow out slowly from the tube and a loud sound is heard when the air

column in the tube is 33 cm.



Calculate the speed of sound.

(338 ms^{-1})

- 13.4 Calculate the wavelength of sound produced by a tuning fork of frequency 512 Hz. Whereas the speed of sound is 340 ms^{-1} .

(66 cm)

14

SPHERICAL MIRRORS AND LENSES

In this chapter you will learn:

1. Reflection of light.
2. Spherical mirror formula.
3. Laws of refraction.
4. Real and apparent depth.
5. Refraction through a prism and its refractive index.
6. Propagation of light in small optical fibre.
7. Primary and secondary rainbow.
8. Lens formula.
9. Defects of lens.
10. Defects of vision.



Spherical Mirrors and Lenses

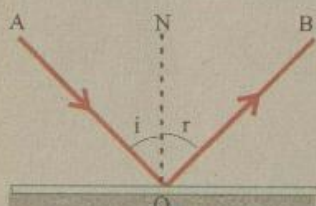


Fig. 14.1: Reflection of light from plane mirror.

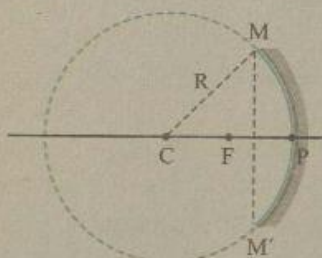


Fig. 14.2(a)

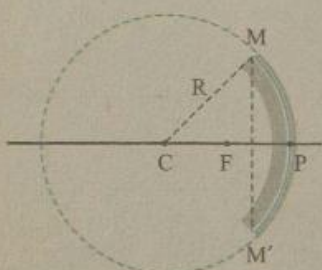


Fig. 14.2(b)

The study of light has been a subject of great speculation even in the ancient times but for the first time an Arab Muslim scientist, IBN-UL-HAITHAM studied it on scientific grounds. He discovered the laws of reflection experimentally. He also studied the phenomenon of refraction of light and he recognized that angle of incidence and angle of refraction had some relation with each other. This relation was discovered six hundred years later by Willebrord Snell, a Dutch scientist. You have studied two properties of light, reflection and refraction in your previous classes. You have also studied that light travels in a straight line. In this chapter we shall study about the reflection from spherical mirrors and lenses.

14.1 REFLECTION OF LIGHT

You know that reflection of light obeys the following laws:

- (i) The angle of incidence i is equal to the angle of reflection r (Fig 14.1).
- (ii) The incident ray, the reflected ray and normal at the point of incidence, all lie in the same plane.

The reflection from spherical mirrors also obeys the above two laws.

14.2 SPHERICAL MIRRORS

As we already know, a spherical mirror, in fact is a portion of the reflecting surface of a hollow sphere. Spherical mirrors are of two types:

1. Concave Mirror
2. Convex Mirror

Concave mirror is that whose inner curved surface is reflecting

(Fig 14.2-a), convex mirror is that whose outer curved surface is reflecting (Fig 14.2-b).

The centre C of the sphere, of which a concave mirror or convex mirror is a part is known as the "Centre of Curvature" of the spherical mirror and the "Radius of Curvature" R of the mirror is the radius of this sphere. The front section of spherical mirror is circular one and its diameter is known as the "Aperture".

Principal Axis

The centre P of the mirror is called the pole of the mirror. A line joining the pole P of the mirror and C, the centre of curvature, is called the "Principal Axis" of the mirror.

The Principal Focus

Rays of light parallel to the principal axis after reflection from a concave mirror converge to a point F. This point is called the "Principal Focus" of the mirror (Fig. 14.3-a). Since rays, in fact, pass through this point, therefore, it is called real focus. In the case of a convex mirror, rays parallel to the principal axis after reflection appear to come from a point F situated behind the mirror. This point is called the principal focus of the convex mirror. The principal focus of a convex mirror is virtual focus because the reflected rays do not actually pass through it but appear to do so (Fig. 14.3-b). Therefore, its focus is called virtual focus.

The distance between the pole and the principal focus of a spherical mirror (concave as well as convex) is called the "Focal Length". It is denoted by f . The radius of curvature of a spherical mirror is twice of its focal length i.e.,

$$f = \frac{R}{2}$$

14.3 SPHERICAL MIRROR FORMULA

The characteristics and location of an image formed by a spherical mirror can be determined from an equation which is called spherical mirror formula.

Concave Mirror Formula

To derive mirror formula consider Fig. (14.4) where an object OA, is placed in front of a concave mirror. A ray of light starting from the end point 'A' of the object and moving parallel to the principal axis strikes the mirror at the point 'E'. It is reflected at 'E' and passes through the principal focus 'F'. A second ray also starting from 'A' falls on the mirror at pole 'P'. It is reflected making an angle of reflection equal to the angle of incidence and intersects the first reflected ray at the point B. Thus point B is the real image of point A.

If this process is repeated for other points of the object OA then a real image IB of the object OA is obtained.

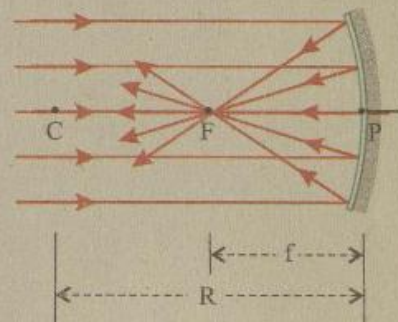


Fig. 14.3(a)

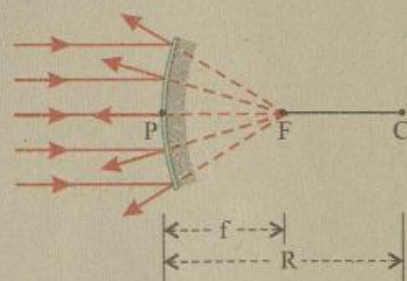


Fig. 14.3(b)

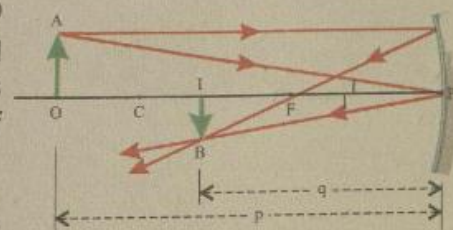


Fig. 14.4

ΔAPO and ΔIPB are similar

$$\frac{AO}{IB} = \frac{OP}{IP} \quad \dots\dots\dots (14.1)$$

Similarly,

ΔIFB and ΔPFE are similar because

$$\frac{PE}{IB} = \frac{FP}{IF}$$

Since

$$PE = AO$$

$$\therefore \frac{AO}{IB} = \frac{FP}{IF} \quad \dots\dots\dots (14.2)$$

Comparing Eq. 14.1 and Eq. 14.2 we get,

$$\frac{OP}{IP} = \frac{FP}{IF}$$

Since

$$IF = IP - FP$$

$$\therefore \frac{OP}{IP} = \frac{FP}{IP - FP}$$

Generally the distance of the object from the mirror is denoted by p and that of image as q . Focal length of the mirror is denoted by f .

Therefore the above equation can be written in the following manner:

$$\frac{p}{q} = \frac{f}{q - f}$$

Or

$$pq - pf = fq$$

$$pq = fq + pf$$

Dividing this equation by pqf we get,

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Convex Mirror Formula

Consider an object OA placed in front of a convex mirror (Fig. 14.5). A ray of light starts from the end point 'A' of the object. It moves parallel to the principal axis. It strikes the mirror at the point 'E' and is reflected in the direction EM . If this ray is produced

backwards (in dotted lines), it meets the principal axis at the principal focus F . This ray appears to diverge from F . Another ray starting from end point 'A' falls on the pole 'P' of the mirror and is reflected making an angle of reflection equal to the angle of incidence. If this ray is produced backwards (in dotted lines), it intersects the first ray at the point 'B'. Thus, point 'B' is the virtual image of 'A'. If this process is repeated for other points of the object OA then the image IB of the object OA is obtained. This image is virtual, erect and diminished.

Using Fig. 14.5, we can prove that the relationship between the object distance p , from the pole, the image distance q from the pole and the focal length of convex mirror f is the same as given by Eq. 14.3 i.e.,

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad \dots\dots\dots (14.6)$$

This equation is known as a spherical mirror formula. Since in case of convex mirror, image is always virtual and according to sign conventions, distance of virtual image is taken as negative and also focal length of convex mirror is taken as negative. Thus the values of f and q are taken as negative.

14.4 LINEAR MAGNIFICATION

The ratio of the height of the image to that of the object is called as linear magnification or simply magnification and is denoted by the letter m . Thus

$$\text{Magnification} = m = \frac{\text{Image height}}{\text{Object height}}$$

Therefore using Eq. 14.1 we can write

$$m = \frac{\text{Image height}}{\text{Object height}} = \frac{IB}{OA} = \frac{IP}{OP} = \frac{q}{p}$$

Example 14.1: An object is placed at a distance of 30 cm from a concave mirror. Find the nature and position of the image if the focal length of the mirror is 5 cm.

Solution: We have

$$p = 30 \text{ cm}, \quad f = 5 \text{ cm}, \quad q = ?$$

Now we find q by using mirror formula

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Substituting the values of p and f we get,

$$\frac{1}{5 \text{ cm}} = \frac{1}{30 \text{ cm}} + \frac{1}{q}$$

$$\text{Or } \frac{1}{q} = \frac{1}{5 \text{ cm}} - \frac{1}{30 \text{ cm}} = \frac{1}{6 \text{ cm}} \quad \therefore q = 6 \text{ cm}$$

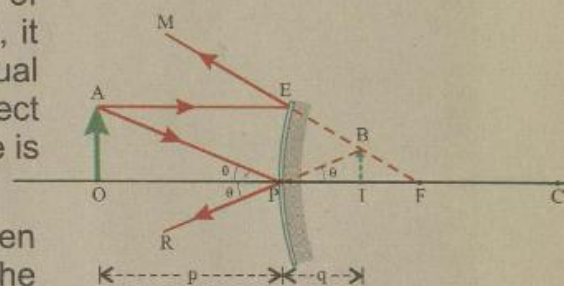


Fig. 14.5

For your Information



In huge shopping centres, convex mirrors are used for security purposes.

Point to ponder



Why convex mirrors are fixed on the blind turns on the roads of the mountains?

For your information



The dentist mirror shows a big and clear view of tooth.

Position of Image: The image is in front of the concave mirror at a distance of 6 cm from the mirror.

Nature of Image: Since q is positive, therefore, image is real.

Example 14.2: How far from a concave mirror of focal length 20cm would you place an object to get an image three times enlarged?

Solution: There are two possible solutions of this question.

(i) When image is real

$$f = 20 \text{ cm}, \quad p = ?$$

As magnification is three times, Thus

$$\text{Magnification} = m = \frac{q}{p} = 3$$

$$q = 3p$$

We have mirror formula

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

By substituting the values

$$\frac{1}{20\text{cm}} = \frac{1}{p} + \frac{1}{3p}$$

$$p = 26.7 \text{ cm}$$

Thus object should be placed at a distance of 26.7 cm from concave mirror.

(ii) When the image is virtual

$$f = 20 \text{ cm}, \quad p = ?$$

$$\text{Magnification} = m = \frac{q}{p} = 3$$

For virtual image $q = -3p$

We have mirror formula

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Substituting the values of q and f in the mirror formula

$$\frac{1}{20\text{cm}} = \frac{1}{p} + \frac{1}{-3p}$$

Or

$$\frac{1}{20\text{cm}} = \frac{1}{p} - \frac{1}{3p}$$

The image is erect $p = 13.3 \text{ cm}$ and behind the mirror.

14.5 USE OF SPHERICAL MIRRORS

Now-a-days the spherical mirrors have a large number of scientific and practical uses. A few uses are as given below:

1. Doctors use concave mirrors for examination of ear, nose, throat and eyes.
2. Concave mirrors with a parabolic shape are used in search light to throw an intense beam of light to a large distance.
3. Some people use a concave mirror for shaving because when a man stands between the principal focus and pole of a concave mirror, he sees an enlarged erect and virtual image of his face. This is the reason why a concave mirror of large focal length is used for shaving.
3. Concave mirrors are used to throw light on the slides of microscope so that the slides can be viewed more clearly.
4. Now-a-days America and other developed countries use giant concave mirrors in their huge telescopes.
5. Convex mirrors are used in motor cycles and automobiles which enables the driver to see the automobiles coming behind him.

14.6 LAWS OF REFRACTION

The refraction of light takes place according to the following two laws:

- (i) The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane (Fig. 14.6).
- (ii) When a ray of light passes from one particular medium to another, the ratio of the sine of the angle of incidence ($\hat{i}$) to the sine of angle of refraction ($\hat{r}$) is constant. This constant ratio is called the "Refractive Index" of the second medium with respect to the first and it is denoted by the letter 'n' i.e.,

$$n = \frac{\sin \hat{i}}{\sin \hat{r}} \quad \dots\dots\dots (14.5)$$

It is called Snell's law. A ray of light entering the second medium perpendicularly through the surface of separation shows no change of direction. Explain why?

Refractive Index

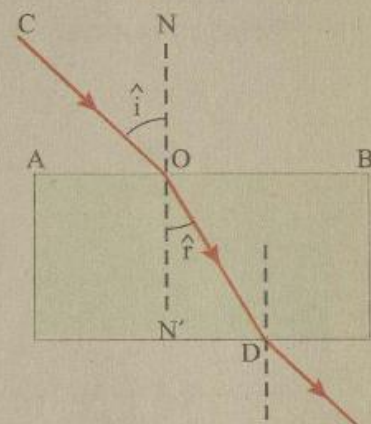
As explained above, when light passes from one medium to another then the constant $= \frac{\sin \hat{i}}{\sin \hat{r}}$ is called the refractive index of the second medium with respect to the first medium.

The refractive index of a medium can also be calculated by dividing the speed of light in vacuum by the speed of light in that medium. As the speed of light in vacuum is almost equal to the speed of light in air, therefore, we use the speed of light in air instead of speed in vacuum, while calculating the refractive index

Do you know ?



Why concave mirror is used for make up or shave ?



Refraction of light
Fig. 14.6

Do you know?

Refractive index of different substances	
Vacuum	1.000
Air	1.0003
Water	1.33
Ice	1.30
Alcohol	1.36
Glycerine	1.47
Crown glass	1.50
Flint glass	1.66
Diamond	2.42

of a medium. For example, the speed of light in glass is $2 \times 10^8 \text{ ms}^{-1}$ and that in air is approximately $3 \times 10^8 \text{ ms}^{-1}$, therefore,

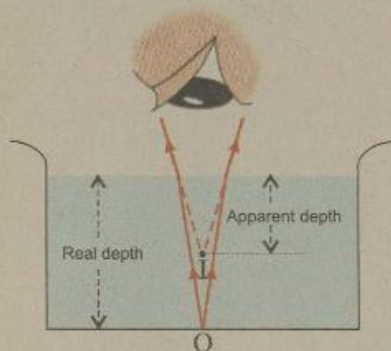
$$\text{Refractive Index of glass with respect to air} = \frac{\text{Speed of light in air}}{\text{Speed of light in glass}}$$

$$n = \frac{c}{v} \quad \dots\dots\dots (14.6)$$

$$= \frac{3 \times 10^8 \text{ ms}^{-1}}{2 \times 10^8 \text{ ms}^{-1}} = 1.5$$

Generally the refractive index of transparent substances is calculated with respect to air. As the speed of light is different in different substances, therefore, different substances have different ability to refract light.

Point to ponder



Why the apparent depth of the pond look less than its real depth?

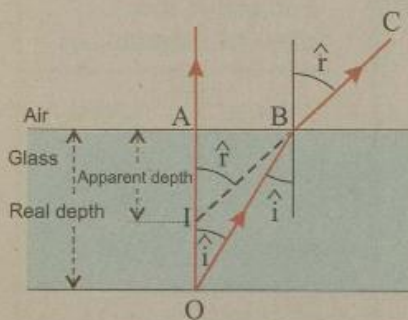


Fig. 14.7

14.7 APPARENT AND REAL DEPTH

A pond of clear water appears to be shallower than it really is. Similarly, the pebbles lying at the bottom of the clear water of a river appear to be raised up above their actual position.

Relation of Refractive Index to Real and Apparent Depth

In Fig. 14.7, O is a bright point below a glass slab. A ray OA from O perpendicular to the surface of the medium passes straight into air. We consider another ray OB from O which is refracted along BC. Air is a rarer medium so angle of refraction is greater than the angle of incidence. When the ray CB is produced backwards, it meets the first ray OA at the point I. For an observer's eye, the object O appears as it were at I above O. Thus I is the virtual image of object O.

Suppose refractive index of glass is n with respect to air. It will have this value in case when light is entering into the glass from air, but in the present case, the light is entering from glass into the air. In this case we can find the refractive index of air with respect to glass by using Snell's law, its value will be $\frac{1}{n}$. Hence

$$\frac{\sin \hat{i}}{\sin \hat{r}} = \frac{1}{n} \quad \text{or} \quad n = \frac{\sin \hat{r}}{\sin \hat{i}}$$

$$= \frac{AB/IB}{AB/OB} = \frac{OB}{IB}$$

when B is very close to A i.e., observer's eye is looking both the rays OA and OB then $IB = IA$ and $OB = OA$

$$\therefore n = \frac{OA}{IA}$$

$$n = \frac{\text{Real depth}}{\text{Apparent depth}} \quad \dots\dots\dots (14.7)$$

Example 14.3: The real depth of a swimming pool is 2m. What is the apparent depth of the pool if the refractive index of water is 1.33?

Solution:

Real depth = 2m , $n = 1.33$, Apparent depth = ?

$$\text{Refractive index of water} = n = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$1.33 = \frac{2\text{m}}{\text{Apparent Depth}}$$

$$\begin{aligned} \text{Thus Apparent depth} &= \frac{2\text{m}}{1.33} \\ &= 1.5\text{m} \end{aligned}$$

14.8 TOTAL INTERNAL REFLECTION

You have studied that when a ray of light passes from a denser (glass) to a rarer medium (air), the refracted ray bends away from the normal and the angle of refraction is greater than the angle of incidence.

It is clear from Fig. (14.8) that as the angle of incidence ($\hat{i}$) increases the angle of refraction ($\hat{r}$) also increases in such a way that ($\hat{r}$) is always greater than ($\hat{i}$), till for a particular value of angle of incidence, the corresponding angle of refraction becomes 90° and the refracted ray grazes along the surface AB (Fig. 14.8).

The angle of incidence in the denser medium for which corresponding angle of refraction is 90° in the rarer medium is called the critical angle. This angle of incidence is denoted by C.

If the refractive index of air with respect to glass is n , then in this case the ray OD is travelling from glass to air and is refracted in air therefore, by applying Snell's law, we will find the value of refractive index, $\frac{1}{n}$

Now for ray OD

According to Snell's law

$$\frac{\sin \hat{i}}{\sin \hat{r}} = \frac{\sin \hat{C}}{\sin 90^\circ} = \frac{1}{n}$$

$$\text{Or } \sin \hat{C} = \frac{1}{n} \quad \dots\dots\dots (14.8)$$

Critical angle C is shown in Fig. (14.8).

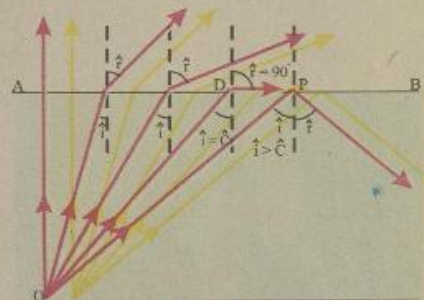


Fig. 14.7

For your information

Material	Critical angle
Glass	42°
Water	49°
Diamond	24°

Do you know ?



In hot summer days, reflections of motor cars are seen on the roads and the image of an aeroplane is seen on the runway, infact there is no water on the runway. It is due to total internal reflection known as mirage.

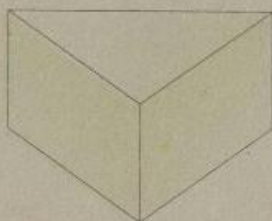


Fig. 14.9(a)

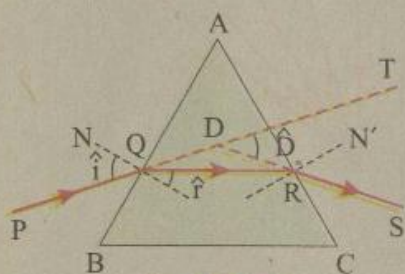


Fig. 14.9(b)

Do You Know?

Periscope is a long tube at the two ends of which are adjusted two totally reflecting prisms. The rays of light from an object are totally reflected through an angle of 90° by each prism. Thus light from a viewed object enters the observer's eye. Periscope is normally used in tanks and submarines. With the help of periscope, the commander of the submarine sitting in his cabin can see the objects on the surface of the sea. Similarly a soldier sitting inside a tank can see the object outside the tank.

When the value of angle of incidence becomes greater than the critical angle then the ray does not pass into the second medium (air) that is the ray of light no longer suffers refraction but all the rays having angle of incidence greater than the critical angle are totally reflected back in the denser medium (glass) obeying the laws of reflection. Such a reflection of light is called "Total Internal Reflection". It is clear from the above discussion that two conditions are essential for the total internal reflection.

- (i) The ray of light should travel from a denser medium to a rarer medium.
- (ii) The angle of incidence should be greater than the critical angle.

14.9 REFRACTION THROUGH A PRISM

Prism is a transparent body having three rectangular and two triangular surfaces as shown in Fig. 14.9 (a). The angle of the triangular surface opposite to its base is known as "Angle of Prism". Fig. 14.9 (b) shows the path of a ray of light refracted through a prism. The incident ray PQ strikes the face AB of the prism. Then on entering the prism the ray bends towards the normal at the point of incidence 'Q' i.e., it bends towards the base of the prism. The refracted ray QR on coming out of the prism, bends away from the normal RN' at the point of emergence R i.e., the emergent ray RS bends towards the base of the prism.

The incident ray PQ makes an angle of incidence $\hat{i}$ and $\hat{r}$ is its corresponding angle of refraction in the prism.

According to the law of refraction

$$n = \frac{\sin \hat{i}}{\sin \hat{r}}$$

where n is the refractive index of the prism. The original direction of incident ray is PQT but it is turned through angle TDS on passing through the prism. The angle TDS is known as angle of deviation. The value of angle of deviation depends upon the value of angle of incidence. When the angle of incidence is continuously increased from a small value, the angle of deviation first decreases, reaches a minimum value and then starts increasing.

The minimum value of the angle of deviation is known as the angle of minimum deviation and is denoted by ' D '. The refractive index ' n ' of the material of the prism with respect to air can be determined by the following relation:

$$n = \frac{\sin \left(\frac{A + D_m}{2} \right)}{\sin \left(\frac{A}{2} \right)} \quad \dots \dots \dots (14.9)$$

where ' A ' is the angle of prism and ' D ' is the angle of minimum deviation.

The refraction of waves depends on their wavelength. Since the sunlight consists of different colours, the waves of different wavelengths, thus when it passes through a prism then the waves of different wavelengths deviate on different paths, due to this white light disperses in different colours, which is called dispersion, and the band of colours which is seen on the screen is called solar spectrum.

14.10 TOTALLY REFLECTING PRISM

A totally reflecting prism is that which has one of its angle equal to 90° and each of the remaining two angles equal to 45° . Here the phenomenon of total internal reflection is used. The critical angle of glass is 42° . If a ray of light strikes one of its faces perpendicularly, it enters the prism without any change of direction and meets the hypotenuse at an angle of 45° so the angle of incidence is also 45° . As it is greater than the critical angle of the glass, the ray will be totally reflected, the angle of reflection being 45° . This reflected ray thus strikes the other face perpendicularly and comes out of the prism. The ray is thus deviated through an angle of 90° . Fig. 14.10 (a) shows rays coming from the object AB are deviated through an angle of 90° and emerge at the prism as A'B'. Due to this fact the prism is used in periscope. Fig. 14.10 (b) shows how a totally reflecting prism deviates the incident ray coming from the object AB through an angle of 180° and emerges out of the prism as A' B' after the twice total internal reflections inside the prism. Due to this fact this prism is used in "Prism Binocular". A prism Binocular is made by using two telescopes separated at a distance equal to the distance between the two eyes.

In Fig. 14.10 (c), this prism is used to erect the image of an object i.e., to invert the rays coming from an object. For example such a prism placed in front of a projector will show an erect image on the screen of an inverted slide or film placed on the other end of the projector.

14.11 OPTICAL FIBRE

In recent years an important and interesting application of principal of total internal reflection is used in optical fibres. As shown in Fig. 14.11, an optical fibre is made of a highly transparent fine strand of glass or plastic coated or cladded with another type of glass whose refractive index is less than the inner tube. Generally the refractive index of inner tube is 1.52 and that of outer coating is 1.48.

If light rays enter at one end of an optical fibre at an angle of incidence greater than the critical angle then these rays undergo total internal reflection repeatedly at the walls and come out at the other end without any loss of intensity. Thus, light travels along the fibre no matter how it may be curved and comes out with a high

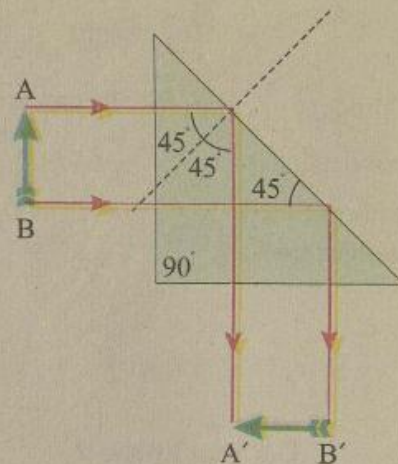


Fig. 14.10(a)

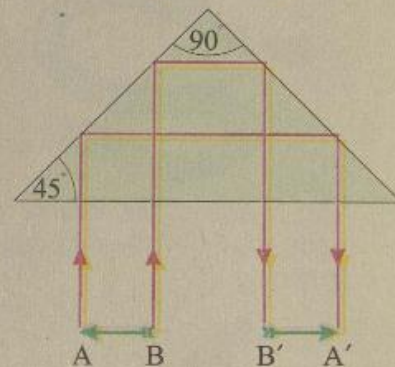


Fig. 14.10(b)

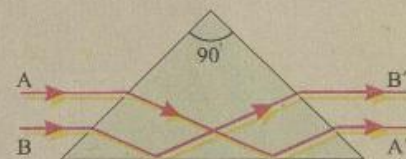
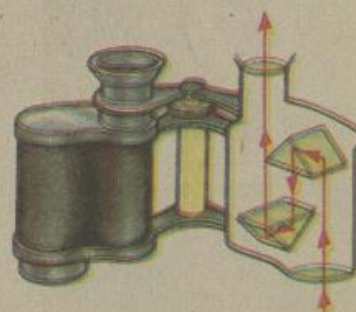
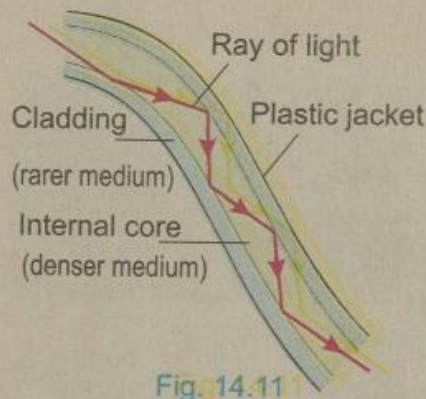


Fig. 14.10(c)

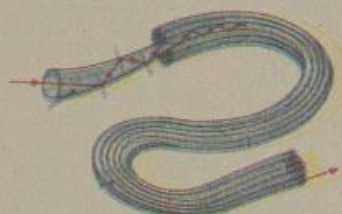
For your information



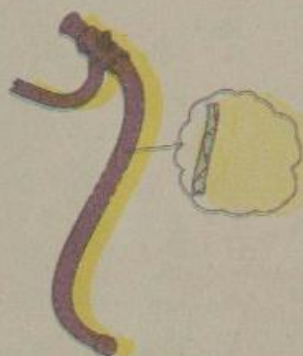
Totally reflecting prisms are used in binocular.



Do you know ?



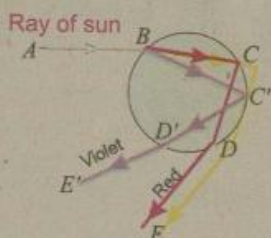
The image of the interior of body can be seen through light pipes.



Endoscope



Rainbow-a natural phenomenon



Primary rainbow
Fig. 14.12(a)

Light Pipes

If several thousands of fine strands of optical fibres are bundled together then a flexible light pipe is obtained which can be used by doctors and engineers to illuminate those inaccessible places which otherwise are not possible to examine.

Like other developed countries of the world, Pakistan is also using optical fibres in telecommunication and other modern communication systems. A single strand of optical fibre can transmit thousands of telephone calls at the same time without interfering each other. Optical fibres are highly flexible and light in weight they are also much cheaper as compared to copper cables. Generally, a cable consists of a bundle of 30 optical fibres. The transmitting capacity of light pipes is thousands of times greater than the radio waves.

Endoscope

Endoscope is such an instrument which is used for viewing and photographing of the internal structure of human body by using light pipes. Endoscope consists of many different types of instruments. A few of these are as follows. For example, 'Gastroscope' is an instrument to view the stomach. 'Branchoscope' is to examine the sore throat and 'Cystoscope' to examine liver. In endoscope by using a bundle of optical fibres, the affected part of the body is illuminated and it is viewed by another bundle of optical fibres. A video camera is fitted outside this bundle and this makes the interior visible to the surgeon which helps him to diagnose easily.

14.12 RAINBOW

Sometimes an arc of spectral colours appears in the sky after a rainfall. This is called rainbow. The viewers can see the rainbow only when the Sun is at the back of the observer and the Sun rays fall obliquely which is possible only in the morning or evening. Rainbow is the most beautiful and colourful natural phenomenon which had been fascinating man from ancient times.

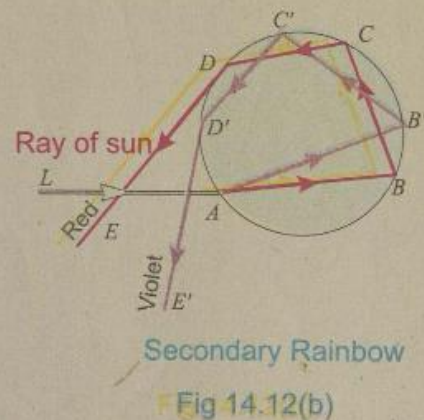
In reality rainbow is a solar spectrum produced due to the dispersion of light. After the rain, innumerable droplets of water remain suspended high up in the air. When Sun rays fall on these droplets, each droplet behaves like a prism and light rays entering the drops suffer refraction and total internal reflection. Since these rays are of white light so they split up into seven colours.

Primary Rainbow

The rainbow described above has brightest colours and is easily visible. This is called "Primary Rainbow". In this case light suffers only one internal reflection in rain drops (Fig. 14.12-a). The primary rainbow has red colour on its outer edge and violet colour on its inner edge. The order of the colours present in the primary rainbow are red, orange, yellow, green, blue, indigo and

Secondary Rainbow

Sometimes a secondary rainbow beyond the outer edge of the primary rainbow is seen. Secondary rainbow is fainter than the primary rainbow and is seldom visible. This is produced when the rays from the sun suffer double internal reflections. Due to two internal reflections in the water droplets cause the colour bands of the secondary rainbow to be in reverse order than in the primary rainbow i.e., the outer edge of the secondary rainbow is violet and the inner edge is red. Thus in the secondary rainbow the order of the colours is violet, indigo, blue, green, yellow, orange and red.



14.13 LENS FORMULA

First of all you should revise your knowledge from your previous class book about lenses, its types and formation of image by a lens.

To study the characteristics and locations of an image formed by a lens, an equation can be derived which is called the "Lens Formula".

Convex Lens Formula

Consider Fig. 14.13 where an object OA, is placed in front of a thin convex lens. A ray of light starting from the end point A and moving parallel to the principal axis strikes the lens at the point E. After refraction through the lens it passes through the principal focus F. A second ray AC also starting from A passes through the optical centre of the lens and moves straight (undeviated) and intersects the first refracted ray at the point B. Thus B is the real image of point A. If this process is repeated for other points of the object OA then a real image IB of the object OA is obtained. Generally the distance of the object from the lens is represented by p and that of image by q . In Fig. 14.13 $\triangle OAC$ and $\triangle IBC$ are similar because $\angle ACO = \angle BCI$. Also one angle in each triangle is 90° so the third will also be equal.

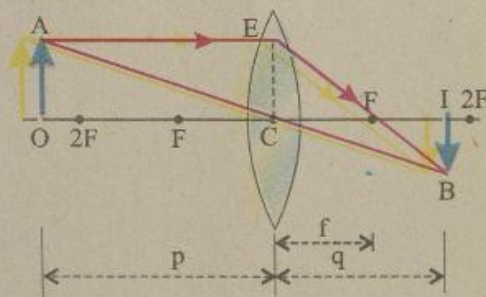


Fig 14.13

$$\therefore \frac{AO}{BI} = \frac{OC}{CI} \quad \dots\dots\dots (14.10)$$

Similarly $\triangle EFC$ and $\triangle BFI$ are similar.

$$\begin{aligned} \therefore \frac{CE}{BI} &= \frac{CF}{FI} \\ \therefore EC &= AO \\ \therefore \frac{AO}{BI} &= \frac{CF}{FI} \quad \dots\dots\dots (14.11) \end{aligned}$$

Comparing Eq. 14.10 and Eq. 14.11 we get,

$$\begin{aligned} \frac{OC}{CI} &= \frac{CF}{FI} & \therefore FI &= CI - CF \\ \frac{OC}{CI} &= \frac{CF}{CI - CF} \end{aligned}$$

Now $CI = q$, $OC = p$ and $CF = f$

$$\therefore \frac{p}{q} = \frac{f}{(q - f)}$$

$$fq = p(q - f)$$

Or $fq = pq - pf$

Dividing both sides by pqf , we get

$$\frac{1}{p} = \frac{1}{f} - \frac{1}{q}$$

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad \dots\dots (14.12)$$

Equation 14.12 represents the relation between distance q of the image formed by a convex lens, distance of the object p from the convex lens and its focal length f .

Concave Lens Formula

Consider Fig. 14.14 where an object OA is placed in front of a thin concave lens. A ray of light starting from the end point A and moving parallel to the principal axis strikes the lens at the point E . This ray is refracted along ER . A second ray AC also starting from A passes through the optical centre of the lens and is refracted straight along its own path. When the ray RE is produced backwards, it appears to intersect the first ray at the point B . Thus B is the virtual image of A . If this process is repeated for the other points of the object OA then the virtual image IB of the object OA is obtained. This image is virtual, erect and diminished.

Since a concave lens always gives virtual image irrespective of the distance of the object from it. Therefore, according to sign conventions, the distance of the virtual image is taken as negative and that of focal length is also taken as negative. Therefore by putting negative sign for q and f we get,

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

This equation is known as lens formula.

14.14 LINEAR MAGNIFICATION

The ratio of the height or size of the image to that of the object is known as "Linear Magnification" or simply magnification and is denoted by the letter m .

$$\text{Magnification} = m = \frac{\text{Image height}}{\text{Object height}}$$

Therefore using Eq. 14.12 we get,

$$\text{Magnification} = m = \frac{\text{Image height}}{\text{Object height}} = \frac{BI}{OA} = \frac{CI}{OC} = \frac{q}{p} \quad \dots (14.13)$$

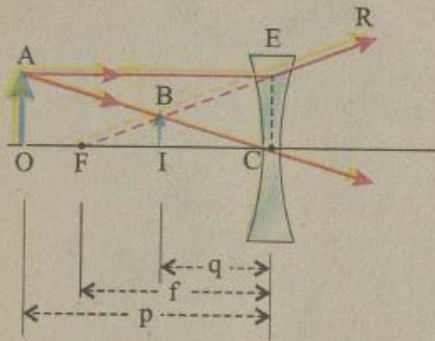


Fig. 14.14

The following sign convention is used in case of lenses.

- (i) All the distances are measured from the optical centre of the lens.
- (ii) The distance of the real objects and real images are taken as positive and those of virtual objects and virtual images are taken as negative.
- (iii) The focal length is taken as positive for convex lens and negative for concave lens.

Example 14.4: The focal length of a convex lens is 20 cm. Where should an object be placed so as to get an image magnified four times?

Solution: Two cases arise

(i) When image is real and (ii) When image is virtual

(i) For real image

In this case $f = 20$ cm, $p = ?$

Since the magnification of the object is four times, thus

$$\text{Magnification} = \frac{q}{p} = 4$$

$$\therefore q = 4p$$

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Therefore,

$$\therefore \frac{1}{20 \text{ cm}} = \frac{1}{p} + \frac{1}{4p}$$

$$p = \frac{20 \text{ cm} \times 5}{4} \\ = 25 \text{ cm}$$

(ii) For virtual image

In this case

$f = 20$ cm, $p = ?$

Since magnification of the object is four times, thus in case of virtual image

$$q = -4p$$

Since

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

Therefore,

$$\frac{1}{20 \text{ cm}} = \frac{1}{p} - \frac{1}{4p}$$

$$p = \frac{20 \text{ cm} \times 3}{4} = 15 \text{ cm}$$

In this case object should be placed at a distance of 15 cm from the lens.

Example 14.5: An object is situated at a distance of 10 cm from a concave lens of focal length of 15 cm. Calculate the position, nature and magnification of the image.

Solution: Object is real, therefore

$$p = +10 \text{ cm}$$

Focal length of a concave lens is taken negative, therefore

$$f = -15 \text{ cm}$$

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{-1}{15 \text{ cm}} = \frac{1}{10 \text{ cm}} + \frac{1}{q}$$

$$q = -6 \text{ cm}$$

Thus the image is 6 cm from the lens on the same side of the object. It is virtual and erect.

$$\text{Magnification} = m = \frac{q}{p} = \frac{6 \text{ cm}}{10 \text{ cm}} = 0.6$$

The size of the image is 0.6 times of the object.

14.15 ABERRATIONS OR OPTICAL DEFECTS OF A LENS

There are two main types of aberrations or optical defects in images produced by a lens.

1. Spherical Aberration.
2. Chromatic Aberration.

1. Spherical Aberration

It is observed that the rays of light which pass through thick lenses or lenses of large aperture do not focus at a single point. Thus the images formed are not sharp and well defined. This defect is called "Spherical Aberration".

If parallel rays of monochromatic light are incident on a lens then the rays near the rim of the lens (called marginal rays) after refraction come to focus at a point F_m nearer to the lens but the parallel rays near the axis (i.e., Paraxial Rays) are focused at point F_p (Fig. 14.15). The second point F_p is farther from the lens than the point F_m . On account of this defect images formed are not sharp or well defined.

This defect is minimized by covering the lens with a disc of size equal to the lens and having a small hole at the centre of this disc. This disc allows only the central or paraxial rays to pass through the central part of the lens but cut off the marginal rays

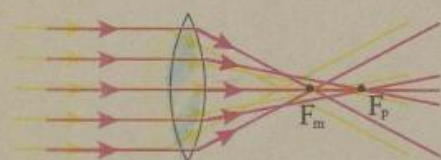


Fig. 14.15



Fig. 14.16

expensive instruments this defect is removed by using a complicated lens made by combining lenses of different shapes.

2. Chromatic Aberration

You might have noted that an object illuminated by white light and viewed through a cheap convex lens shows coloured tinge in the image. This makes the image blurred.

A lens acts like two prisms placed end to end. Thus white light while passing through a lens is refracted as well as dispersed. As a result violet rays are focussed nearest than the red rays are focussed at the farthest away (Fig. 14.17). This defect is called chromatic aberration. It can be minimized by combining a convex lens of crown glass and a concave lens of flint glass in such a way that dispersion of light produced by the convex lens is neutralized by the concave lens. Such a combination of lenses is called an "Achromatic Lens" (colour corrected lens) (Fig. 14.18). In high class cameras and optical instruments a complicated combination of lenses is used.

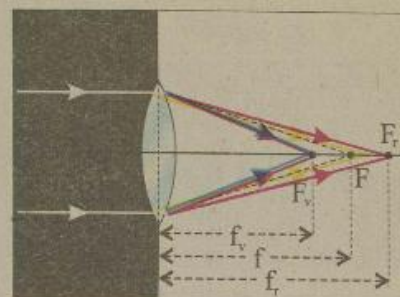


Fig. 14.17



Fig. 14.18

14.16 POWER OF A LENS

If the focal length of a lens is f then its reciprocal ($\frac{1}{f}$) is called the power of the lens. Thus

$$\text{Power of the lens} = p = \frac{1}{f}$$

When f is measured in metres then power of the lens is in 'Dioptries'. The unit of power "Dioptry" is defined as the power of a lens of focal length of one metre. Its symbol is 'D'.

Because the focal length of a convex lens is positive ($+f$) therefore the power of convex lens is also positive.

Whereas the focal length of a concave lens is negative therefore the power of a concave lens is negative. Opticians and eye specialists refer to the power of a lens instead of its focal length for their patients.

14.17 DEFECTS OF VISION

A normal eye can see objects clearly at a far off distance down to about 25cm from the eye. But for many people it is not possible. There are two main defects of human eye.

1. Short Sightedness
2. Long Sightedness

1. Short Sightedness

A man suffering from short sightedness cannot see distant objects clearly but can see near objects clearly. This defect may be due to that either the lens of the eye ball is thick (i.e., short focal length) or the eye ball is longer than the suitable size. For this reason the image of distant object is formed in front of the retina instead of at retina (Fig. 14.19-a). The actual far point of such an eye is near the eye instead of infinity (Fig. 14.19-b). Short sightedness can be

Interesting information

Some animals like fish has the ability to move their eye lenses forward or backward and hence, are able to see clearly objects around them.

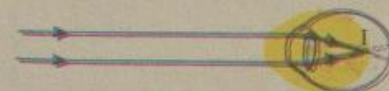


Fig. 14.19(a)



Fig. 14.19(b)



Fig. 14.19(c)

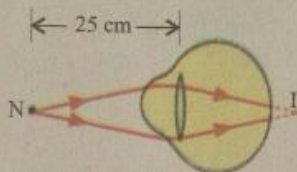


Fig. 14.20(a)

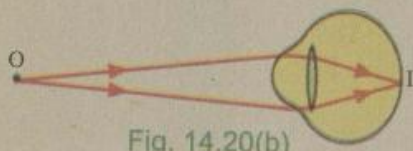


Fig. 14.20(b)

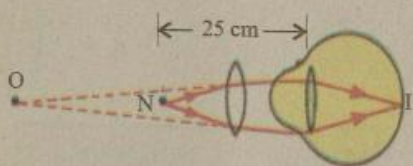


Fig. 14.20(c)

Observe and tell

If you or your friend uses spectacle, observe its lens and tell whether it is convex lens or concave lens and also whether it is being used for long sightedness or short sightedness.

corrected by wearing spectacle having suitable concave lens. Light rays coming from the distant object are now diverged by the concave lens so that they appear to be coming from the eye's own far point F. Therefore rays are focussed on the retina, thus forming a sharp image (Fig. 14.19-c)

2. Long Sightedness

A person suffering from long sightedness cannot see the near objects distinctly but can see the distant objects clearly. This defect may be caused by an eye ball which is shorter than the normal size or eye lens is thinner i.e., less converging. This means that the light rays from near objects are not focussed on the retina but behind the retina (Fig. 14.20-a). A man suffering from long sightedness is unable to read the printed page of a book held at the normal 25 cm from such an eye because the near point of such an eye is greater than 25 cm (Fig. 14.20-b).

Long sight can be corrected by wearing spectacle having convex lens of such a focal length which forms a virtual image of the object placed at normal 25 cm at the near point O of the eye (Fig. 14.20-c). Hence a clear image of the object is formed on the retina.

Example 14.6: The near point of a person is 50 cm and his far point is 200 cm. Calculate the power of the lenses which his spectacles should have (i) for reading (ii) to see clearly the distant objects.

Solution:

The person is suffering both from long sightedness and short sightedness.

(i) Correction of long sightedness

Here

Near point of the person = 50 cm

Normal near point of the eye = $p = 25$ cm

Substituting $q = -50$ cm, $p = 25$ cm in the lens equation.

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{f} = \frac{1}{25 \text{ cm}} - \frac{1}{50 \text{ cm}} = \frac{1}{50 \text{ cm}}$$

$$\therefore f = 50 \text{ cm} = \frac{50 \text{ cm}}{100} = \frac{1}{2} \text{ m}$$

$$\text{Power of the lens} = P = \frac{1}{f \text{ (m)}} = \frac{1}{1/2} = \frac{2D}{1} = +2D$$

Thus for the correction of long sightedness the person should use a convex lens of +2D power.

(ii) Correction of short sightedness

Here $q = -200 \text{ cm}$, $p = \infty$

In the lens equation

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{f} = \frac{1}{\infty} - \frac{1}{200 \text{ cm}} \quad \text{or} \quad f = -200 \text{ cm} = -2 \text{ m}$$

$$\begin{aligned} \text{in power of the lens} = P &= \frac{1}{f \text{ (m)}} = -\frac{1}{2} \text{ D} \\ &= -0.5 \text{ D} \end{aligned}$$

Thus for the correction of short sightedness the person should use a concave lens of 0.5 D power.

Please care



In these days, some people use contact lenses instead of spectacles. A specific cleaning is essential for their usage to avoid any possible infection.

SUMMARY

1. Spherical mirror formula: $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

Focal length f is taken positive for the concave mirror and negative for the convex mirror, q is taken positive for the real image and negative for the virtual image.

2. Linear magnification is the ratio of the height of the image to that of the object. It can also be found from the ratio of the distance of the object to that of image from the mirror.

3. Following are the laws of refraction:

(i) Incident ray, refracted ray and the point of incidence, all lie in the same plane.

(ii) For any two mediums, there is a constant of ratio of the sine of angle of incidence and the sine of angle of refraction is constant. This constant ratio is called refractive index 'n' [of the second medium with respect to first medium].

$$(iii) \quad n = \frac{\sin i}{\sin r}$$

$$(iv) \quad \text{Refractive index of the medium} = \frac{\text{Speed of light in air}}{\text{Speed of light in the medium}}$$

4. When light enters from a denser medium to a rarer medium then the angle of incidence whose angle of refraction becomes 90° is called critical angle.

5. When a ray of light from denser

medium enters a rarer medium in such a way that angle of incidence is greater than critical angle, then the ray is reflected totally inside and does not emerge out from the denser medium. This phenomenon is called total internal reflection.

6. Lens formula: $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$

Focal length f is taken positive for convex lens and negative for concave lens. For real image q is positive and for virtual image, q is negative.

7. The parallel rays of light do not focus at a single point when it refract through a thick lens and lens of large aperture. This defect is called spherical aberration.

8. The image illuminated by a white light through a convex lens shows colours and not well defined. This defect is called chromatic aberration.

9. The reciprocal of the focal length of a lens in metres is called power of lens and its unit is diopter.

10. That defect of eye due to which one cannot see the distant objects clearly but can see near objects clearly is called short sightedness. To remove this defect, a concave lens of a suitable power is used.

11. The defect of eye due to which one cannot see the near objects clearly and can see the distant objects clearly is called long sightedness. To remove this defect, a convex lens of a suitable power is used.

QUESTIONS

144.1 What are spherical mirrors? How light is reflected from spherical mirrors? Give the uses of spherical mirrors.

144.2 Derive the mirror formula. For the concave and convex mirrors which quantities are taken as positive and negative?

144.3 What is meant by refraction of light? Explain in some detail the refraction of light through a prism.

144.4 What is meant by apparent and real depth? How can we find the refractive index by it?

144.5 What is meant by critical angle? Describe total internal reflection and conditions necessary for it.

144.6 What are the optical fibres? On which principle they work? Describe their few uses.

144.7 What are the main defects of the eye and how are they corrected?

144.8 By which phenomena of light, rainbow is seen? What is difference of the primary and secondary rainbow?

144.9 Drive the lens formula of a thin convex lens. Also write down conventions about the focal length and distances of object and image.

144.10 Explain the defects of a lens. How can they be minimized?

144.11 Mark (✓) on correct answer of the following questions:

(i) Focal length of the concave mirror

(a) is positive (b) is negative

(c) is greater (d) is smaller

(ii) Linear magnification

(a) is the ratio of the distances of object and image from mirror.

(b) is the ratio of the distances of object and image from the focal point.

(c) is the ratio of the distances of the image and object from mirror.

(d) is the ratio of the distance of image from object and the distance of object from mirror.

(iii) Focal length of a concave lens

(a) is positive (b) is negative

(c) is greater (d) is smaller

(iv) If the image is virtual, then its distance from lens

(a) is taken positive

(b) is taken negative

(c) is taken double

(d) is taken half

144.12 Give the short answers of the following questions:

(i) Which lens is used for the long sightedness?

(ii) To remove the defect of chromatic aberration which method is used?

(iii) To get a greater and clear image at what distance lens should be placed from the object?

(iv) What should be angle of incidence for total internal reflection?

(v) Which lens have greater power, either of less focal length or of greater focal length?

NUMERICAL PROBLEMS

- 14.1** An object is placed at a distance of 10 cm from a concave mirror. If the radius of curvature of the concave mirror is 15 cm, determine the position, nature and magnification of the image.
(30 cm, Real inverted image, 3 times the size of the object)
- 14.2** A lighted candle is placed 12 cm from a convex mirror. If the focal length of the mirror is 15 cm and height of the candle is 4.5 cm. Find the position, nature and size of the image.
(6.67 cm, virtual, 2.5 cm)
- 14.3** An object 1 cm high is placed at a distance of 15 cm from a convex lens of focal length 10 cm. Determine the nature, position and size of the image.
(Real, 30 cm and twice in size)
- 14.4** An object 2 cm high is placed in front of a convex lens of focal length 14 cm. Where should the object be placed so as to get a real image 4 cm high?
(21 cm)
- 14.5** An object 6 cm high is placed at a distance of 20 cm from a concave lens of focal length 10 cm. Calculate the position, nature and size of the image.
(6.6 cm, virtual image of size 2 cm)
- 14.6** The speed of light in air is 3.0×10^8 ms⁻¹. If the refractive index of the diamond is 2.42 then find the speed of light in it.
(1.24×10^8 ms⁻¹)
- 14.7** The depth of a pond is 4 m. What is the apparent depth of the pond if the water level is 3.5 m high? The refractive index of water is 1.33.
(3.13 m)
- 14.8** The power of a convex lens is 10 D. At what distance the object should be placed from the lens so that its real and 3 times larger image is formed.
(13.3 cm)

In this chapter you will learn:

1. Electric charge and its properties.
2. Construction of electroscope and its uses.
3. Coulomb's law.
4. Electric field and electric intensity.
5. Electric potential.
6. Capacitance and capacitors.

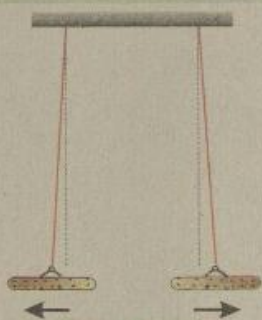


Fig. 15.1(a)

Two glass rods rubbed with silk repel each other.

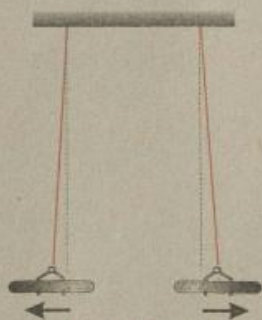


Fig. 15.1(b)

Two ebonite rods rubbed with wool repel each other.

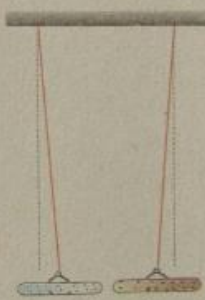


Fig. 15.1(c)

A glass rod rubbed with silk and an ebonite rod rubbed with wool attract each other.

15.1 ELECTRIC CHARGE

When a plastic comb is moved in dry hair, it starts to attract small pieces of paper. Similarly when a glass rod is rubbed with silk cloth or an ebonite rod with a woollen cloth, these rods also begin to attract small particles. We say that these substances have developed the property of attraction because they have acquired electric charge. The following experiment shows that electric charges are of two types:

- i. Rub two glass rods with silk and suspend them, horizontally in a line, close to each other (Fig. 15.1-a). You would see that they repel each other.
- ii. If you repeat this experiment with an ebonite rods after rubbing them with a woollen cloth, you would again see that the two rods repel each other (Fig. 15.1-b).

In the first part of the experiment, as both the rods are of glass and both of them have been rubbed with silk, so we are justified to assume that the charge on both the rods would be of the same kind. Similarly in the second part of the experiment, both the ebonite rods would have the same kind of charge. Hence we conclude from this experiment that like charges repel each other.

- iii. Now suspend the glass rod rubbed with silk near an ebonite rod rubbed with wool, this time the two rods attract each other (Fig. 15.1-c). This shows that the charge on the two rods are not of the same kind and their nature is opposite. Therefore, in order to differentiate between the two kinds, we call the charge on glass rod positive and that on ebonite rod, negative. From this part of the experiment we conclude that unlike charges attract each other. The charge on glass and ebonite rod, is in fact, due to the presence of positive and negative charged particles. The glass rod rubbed with silk has a large number of positive particles, whereas an ebonite rod rubbed with wool has a large number of negative particles. Now question arises, from where these positive and

negative particles have appeared? The answer to this question can be given by considering the structure of an atom, the fundamental particle of matter. The atom of an element consists of two parts one is its central part, known as nucleus. It consists of protons and neutrons. The charge on a proton is positive, while the neutron has no charge. The second part of the atom consists of electrons which are moving outside the nucleus in various orbits. The electron has a negative charge. The charge on a proton and that on an electron are equal in magnitude but opposite in kind. The atom as a whole is neutral. This would be possible only when the number of proton and electrons present in an atom are equal. We know that there is a force of attraction between positive and negative charges. So there exists a force of attraction between the protons present in the nucleus and the outside orbiting electrons. Due to this force of attraction the electrons are constrained to move in their respective orbits, which they cannot leave. But as the distance of orbits from the nucleus increases the force of attraction between the nucleus and the electron decreases. Hence the electrons in the outermost orbit are bound in the orbit with a very weak force. Such electrons can be separated from their respective atom by a small externally applied force. When the ebonite rod is provided an external force by rubbing with wool, the loosely bound electrons in the wool are transferred to ebonite rod. As electrons carry negative charge, therefore a negative charge is developed on the ebonite rod. When glass rod is rubbed with silk, the loosely bound electrons of glass are transferred to silk, due to which number of electrons in the glass gets deficient. So it shows a positive charge.

Solid bodies are charged due to the transfer of electrons. In general a solid body is neutral. If electrons are transferred to it, it gets negative charge. If electrons leave it, it gets positive charge. In metallic substances, the electrons in the last orbit are so loosely bound that their motion is no longer confined to its orbit but instead they can move freely through the whole body of the metal. These are known as free electrons and they can be easily transferred to other bodies.

15.2 ELECTROSTATIC INDUCTION

In Fig. 15.2, PQ is a metallic body which is mounted on an insulated stand. If a negatively charged ebonite rod is brought near its end P, tests will reveal the presence of negative charge at the end Q and positive charge at the end P. When the ebonite rod is removed away the charge on PQ also vanishes showing that the charge on PQ appears only in the presence of the charged ebonite rod.

If in the presence of a charged body, an insulated conductor has like charges at one end and unlike charges at the other end then this is called the electrostatic induction.

For Your information

In the table given below, different materials have been arranged in such a way that if any of the two materials are rubbed together the material occurring first in the list would have positive charge and that occurring next would have negative charge. For example, among cat's skin and glass, skin has positive charge whereas glass has negative charge.

1. Asbestos
2. Glass rod
3. Mica
4. Woollen cloth
5. Cat's skin
6. Lead
7. Silky cloth
8. Aluminium
9. Cotton cloth
10. Wood
11. Copper rod
12. Rubber
13. Plastic

Do you know?

Innumerable electrons strike against the inner surface of the picture tube of a T.V. set but in spite of it, the body of the set does not show any charge. Actually a conducting paint is coated on the inner surface of the screen which continuously transfers the electrons to ground and does not allow them to accumulate on the screen.

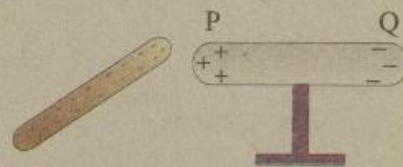


Fig. 15.2: Electrostatic Induction

In this phenomenon all charges remain static that is why it is known as electrostatic.

This phenomena can be explained in terms of free electrons. The negative charges present on the ebonite rod repel the free electrons to the electrons at the end Q. In this way the end Q gets negatively charged and a deficiency of electrons occurs at the end P due to which it shows positive charge. The quantity of negative charge at Q is equal to the quantity of positive charge appearing at P. That is why when the negative charged on ebonite rod is removed, the repelling force acting on free electrons vanishes and free electrons spread uniformly on the whole of the conductor. Due to uniform distribution of free electrons, the deficiency of electrons at the end P and the excess of electrons at the end Q no longer exists.

15.3.3 ELECTROSCOPE AND ITS USE

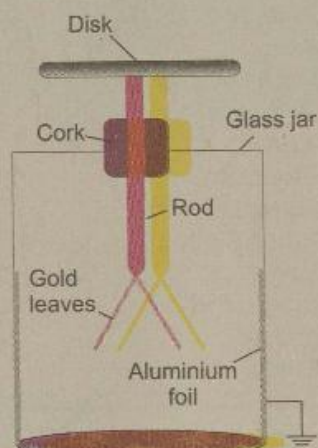
It is an instrument used for detecting and testing the nature of charge on a body.

It consists of a brass rod which has a brass disc connected to its upper end and two very thin gold leaves attached its lower end. By the help of a cork this assembly is mounted inside a glass jar with the brass disc projecting outside as shown in Fig. 15.3. A thin aluminium foil is pasted on the lower portion of the inner surface of the jar. Usually this foil is grounded by means of a copper wire. When any charge is transferred to electroscope, it spreads in the discs and the leaves. Due to force of repulsion between similar charges on the leaves, they diverge. The divergence of the leaves depends upon the quantity of charge on the leaves.

In order to detect the presence of charge on a body, bring it near the disc of an uncharged electroscope. If the body is charged the leaves of the electroscope involved diverge otherwise they would remain in their normal position (Fig. 15.4).

The divergence in the leaves of the electroscope due to the presence of a charged body is due to electrostatic induction. Suppose the body which is brought near the electroscope has negative charge. Due to induction positive charges will appear on the disc and negative charges on the leaves. As like charges repel each other, therefore, due to the force of repulsion between the negative charges present on the two leaves, they will diverge (Fig. 15.5).

In order to detect the kind of charge on a charged body, the electroscope will have to be first charged either with positive charge or with negative charge. In order to charge the electroscope positively, touch its disc with a positively charged body. If it is to be negatively charged touch its disc with a negatively charged body. In this process a portion of the charge present on the body is



Electroscope
Fig. 15.3.3

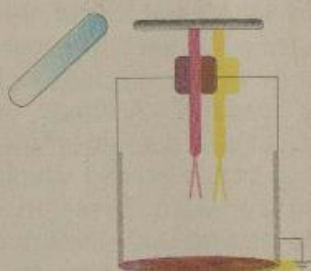


Fig. 15.4.4

If an object is uncharged, the leaves remain in normal position.

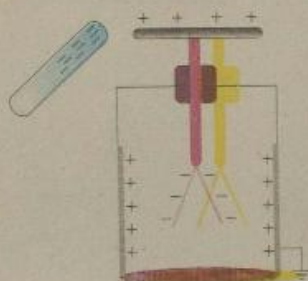


Fig. 15.5.5

The leaves diverge due to the pressure of similar charge.

transferred to the disc and the leaves of the electroscope. After charging the electroscope bring the body under test near the disc of the electroscope, if the divergence of leaves increases the body has the same kind of charge as on the electroscope. On the other hand if the divergence decreases, the charge on the body will be opposite to the kind present on the electroscope.

Electroscope can also be used to distinguish between insulators and conductors. Touch the disc of a charged electroscope with body under test. If the leaves collapse from their diverged position the body would be a good conductor. If there is no change in the divergence it will show that the body is an insulator. However a gradual collapse will indicate that the body is not a good conductor.

15.4 COULOMB'S LAW

A force of attraction or repulsion acts between two charged bodies. How is this force affected when the quantity of the charge on the two bodies or the distance between them is changed? In order to find the answer of this question, a "French scientist Charles Coulomb" performed a number of experiments and found that:

The force of attraction or repulsion between two charged bodies is directly proportional to the product of the quantity of charges on them and inversely proportional to the square of the distance between them.

This law is known as Coulomb's law after the name of its discoverer.

If the distance between two charged bodies is much greater as compared to their size, the bodies are considered as point charges. Fig. 15.6 shows the force acting on two point charges q_1 and q_2 . F_{12} is that force which the charge q_1 experiences due to q_2 and F_{21} is the force on q_2 due to q_1 . Both these forces F_{12} and F_{21} are known as Coulomb's force. They always act along the line joining the two point charges. Fig. 15.6 (a,b) shows the two forces when the charges are of the same kind and Fig. 15.6 (c) shows the forces when they are of opposite kinds. The coulomb's forces F_{12} and F_{21} have equal magnitude but always act in opposite directions.

Usually the Coulomb's force is represented by F .

If the distance between two point charges q_1 and q_2 is r , Coulomb's law can be, mathematically, written as

$$F \propto \frac{q_1 q_2}{r^2}$$

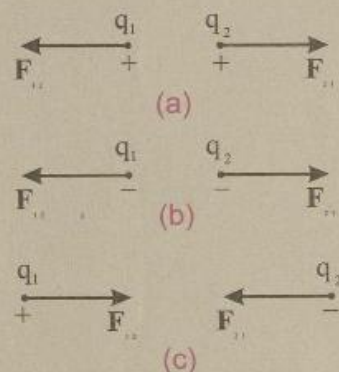
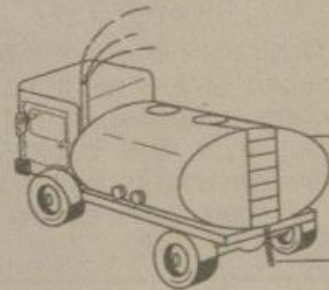


Fig. 15.6

Coulomb's force between two point charges q_1 and q_2

Interesting Information



A metallic chain can be seen hanging from the rear side of a petrol supply tanker. This chain rolls on the road as the tanker moves. Due to friction with air, the body of tanker gets charged and tiny spark can cause a havoc. This charge is continuously being transferred to ground through the metallic chain. Thus the danger of spark is eliminated.

For your Information

SI unit of charge is known as coulomb. It is equal to the charge of 6.25×10^{18} electrons. This is a very big unit. Usually the charge is measured in micro coulomb (C). It is given by $1\mu\text{C} = 10^{-6}\text{C}$.

Or

$$F = k \frac{q_1 q_2}{r^2} \quad \dots\dots\dots (15.1)$$

where k is a constant whose value depends upon the medium between the two charges and the system of units in which F , q and r are measured.

In SI system, if the medium between the two charges is space or air then in this case the value of k will be $9 \times 10^9 \text{ Nm}^2 \text{C}^{-2}$.

In order to show the dependence of k upon the medium, usually it is expressed in terms of a property of medium known as permittivity. In case of free space it is represented by ϵ_0 . The relation between k and ϵ_0 is given by

$$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2 \text{C}^{-2}$$

By substituting the value of k

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \quad \dots\dots\dots (15.2)$$

By using Eq. 15.2, we can find the force between two point charges placed in free space or air.

Example 15.1: Two bodies are oppositely charged with $500\mu\text{C}$ and $100\mu\text{C}$. Find the force between the two charges if the distance between them in air is 0.5m .

Solution:

$$q_1 = 500\mu\text{C} = 500 \times 10^{-6}\text{C}$$

$$q_2 = 100\mu\text{C} = 100 \times 10^{-6}\text{C}$$

Distance between the charges $= r = 0.5\text{m}$

Substituting the values in equation of Coulomb's law

$$\begin{aligned} F &= \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \\ &= 9 \times 10^9 \text{ Nm}^2 \text{C}^{-2} \times \frac{500 \times 10^{-6}\text{C} \times 100 \times 10^{-6}\text{C}}{(0.5\text{m})^2} \\ &= 1800\text{N} \end{aligned}$$

Do you know?

During flight, body of an aeroplane gets charged. Its tyre are of some conducting material. As the aeroplane lands, this charge is easily transferred to ground and the danger of sparking is eliminated while petrol is filled in it.

15.5 ELECTRIC FIELD

If a charge q is brought near a charge Q placed, somewhere in space, the charge q will experience a force. According to Coulomb's law the value of this force would depend upon the distance between the two charges. If the charge q is moved away from Q this force would decrease till at a certain distance the force would practically reduce to zero. Now the charge q is out of the

influence of charge Q . This region of space surrounding the charge Q in which it can exert a force on a charge q is known as electric field of the charge Q . Thus the electric field of a charge is defined as follows:

The electric field of a charge is a region of space surrounding it, in which a charge can feel its electrostatic effect in the form of a force.

The strength of the field at any point is known as electric intensity. In order to find the value of electric intensity at a point in the field, we place a test charge $+q$ at that point. If $\mathbf{F}$ is the force acting upon it, the electric intensity $\mathbf{E}$ would be given by

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

Or $\mathbf{F} = q\mathbf{E}$ (15.3)

Thus the electric intensity at any point is defined as the force acting on a unit positive charge placed at that point.

Electric intensity being a force is a vector quantity. According to Eq 15.3 its direction is the same as that of the force acting on the positive test charge. If the charge q is free, it will move in the direction of electric intensity. In case of negative charge the force would be $\mathbf{F} = -q\mathbf{E}$, so the negative charge would move in a direction opposite to electric intensity.

By using Eq. 15.3 we can find out the electric intensity due to a point charge $+Q$. Suppose a point is located at a distance r from the charge $+Q$ at which the electric intensity is to be determined. We place a point charge $+q$ at this point (Fig. 15.7).

The force acting upon this charge as given by Coulomb's law is

$$F = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2} \quad \text{.....} \quad (15.4)$$

According to Eq. 15.3 this force is also given by $F = qE$.

Therefore, $F = qE = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2}$

Or $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \quad \text{.....} \quad (15.5)$

The electric intensity is directed away from the charge $+Q$ along the line joining the two charges (Fig. 15.7).



Fig. 15.7: A charge q is placed at a distance, from charge $+Q$

Example 15.2: Two points P and Q are located at a distance of 5 cm and 20 cm respectively from a point charge of $+10\ \mu\text{C}$. Find

the magnitude of electric intensity at these points.

Solution:

Quantity of charge = $Q = 10 \mu\text{C} = 10 \times 10^{-6} \text{ C}$

Distance from the charge $P = r_1 = 5 \text{ cm} = 0.05 \text{ m}$

Distance from the charge $Q = r_2 = 20 \text{ cm} = 0.20 \text{ m}$

The constant $k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2}$

$$\begin{aligned} \text{Electric intensity at the distance } r_1 = E_1 &= \frac{1}{4\pi\epsilon_0} \frac{Q}{r_1^2} \\ &= \frac{9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2} \times 10 \times 10^{-6} \text{ C}}{(0.05 \text{ m})^2} \\ &= 3.6 \times 10^7 \text{ NC}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Electric intensity at the distance } r_2 = E_2 &= \frac{1}{4\pi\epsilon_0} \frac{Q}{r_2^2} \\ &= 9 \times 10^9 \text{ Nm}^2 \text{ C}^{-2} \times \frac{10 \times 10^{-6} \text{ C}}{(0.2 \text{ m})^2} \\ &= 2.25 \times 10^6 \text{ NC}^{-1} \end{aligned}$$

It can be seen that the magnitude of electric intensity decreases with the increase of distance.

15.6 ELECTRIC LINES OF FORCE

The direction of electric intensity in an electric field can also be indicated by drawing lines. These lines are known as electric lines of force. They originate from a positive charge and terminate at a negative charge and are such that the tangents drawn at various points on a line give the direction of electric intensity at those points. Fig. 15.8 shows an electric line of force. Tangents drawn at three points A, B, C on this line have been shown by the sign of arrows which indicate direction of electric intensity at these points i.e., if a positive charge is placed at these points, it will move in the direction of these tangents. Fig. 15.9 shows lines of force of some common electric fields.

Fig. 15.9 (a) shows the lines of force due to a positive charge. By electrostatic induction this positive charge induces negative charge on the surrounding body, the lines of force terminate at these charges. The induced negative charge has not been shown in the figure. Similarly Fig. 15.9 (b) also does not show the oppositely induced charge.

The number of the lines of force is also related with the strength of the field. The lines are close together in the region

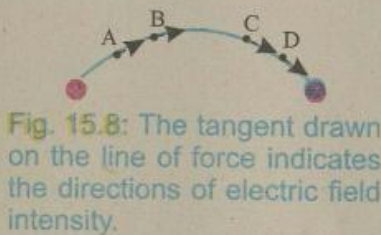


Fig. 15.8: The tangent drawn on the line of force indicates the directions of electric field intensity.

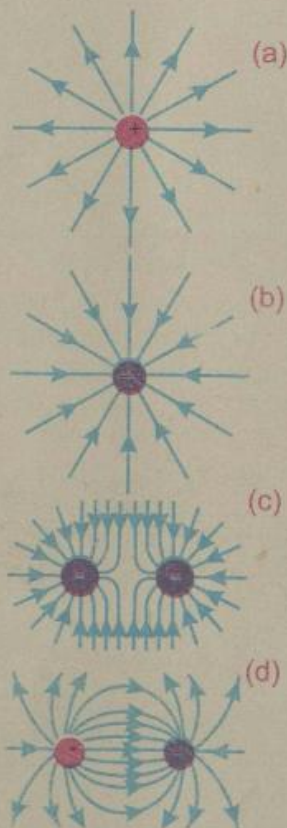


Fig. 15.9: Lines of force of different electric fields.

where the field is strong and are far apart in the weaker regions of the field. Thus, just by seeing the lines of force, we can get information about the magnitude and direction of electric intensity.

15.7 ELECTRIC POTENTIAL

Just like an electric field a charge is also surrounded by a field of electric potential. The potential at any point in the field is defined as the potential energy of a unit positive charge placed at that point which is equal to the amount of work done in bringing a unit positive charge from infinity to that point.

If W is the amount of work done in bringing a test charge $+q$ from infinity to a certain point in the field, the potential V at this point would be given by

$$V = \frac{W}{q} \quad \dots\dots\dots (15.6)$$

Potential is a scalar quantity. Its SI unit is known as Volt. If the potential energy of one coulomb positive charge at a point is one joule, the potential of that point would be one volt.

When we release a body in a gravitational field, it moves from a point of higher potential energy to a point of lower potential energy. Similarly when a charge q is left for free motion in an electric field, it moves from a point of higher potential say A to the point of lower potential say B. If the potential of the point A is V_A and that of B is V_B , the potential energy of the charge at these points would be qV_A and qV_B respectively. The difference of these potential energies $qV_A - qV_B$ is supplied by the charge as it moves from A to B. This energy can be utilized by us in doing different kinds of work. Thus we have the following expression for the energy supplied by a charge,

$$W = q(V_A - V_B) \quad \dots\dots\dots (15.7)$$

If q is equal to one unit, then the potential difference between two points gets equal to the energy supplied by the charge. Thus the potential difference between two points can be defined as the energy supplied by a unit charge as it moves from one point to the other.

If a positive charge is transferred from a point of lower potential to a point of higher potential, energy would have to be supplied to it.

When we release a negative charge in an electric field, its behaviour is just the opposite. It supplies us energy by moving freely from a point of lower potential to a point of higher potential. If we move a negative charge from higher to lower potential we will have to supply energy to the charge by doing work on it.

We can define a new unit of energy known as electron volt (eV)

Do you know?

In 1776, an Italian scientist Alexendro Volta invented the chemical battery. Volt, the unit of potential difference has been named after him.

by noting the fact that the product of charge and potential difference is energy. It is equal to the amount of energy supplied by an electron as it moves between two points having a potential difference of one volt. In Eq. 15.7

$$\text{charge on an electron} = q = 1.6 \times 10^{-19} \text{ C.}$$

$$V_A - V_B = 1\text{V}$$

i.e.,

$$\begin{aligned} 1 \text{ eV} &= 1.6 \times 10^{-19} \text{ C} \times 1\text{V} \\ &= 1.6 \times 10^{-19} \text{ J} \end{aligned}$$

This is a small unit of energy and is often used in atomic and nuclear physics.

15.8 PRACTICAL APPLICATION OF ELECTROSTATIC PHENOMENON

Electrostatic phenomena is used for separation of smoke and other particles from the gases coming out the chimneys of various factories. In these chimneys a wire gauze is fixed between two metallic plates which are grounded (Fig. 15.10). Wire gauze is highly charged with positive charges. By electrostatic induction, negative charges are induced on the inner surface of the metal plates.

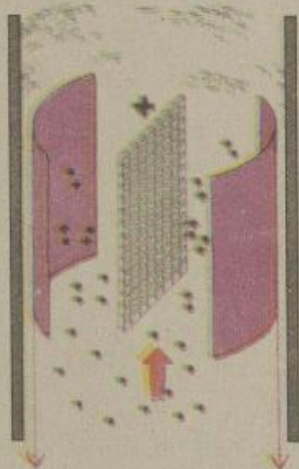


Fig. 15.10



Fig. 15.11

When the gas containing smoke and other particles passes through the space surrounding the positively charged wire gauze, a positive charge is produced on these particles. These positively charged smoke and other particles are attracted by the plate due to the presence of negative charges on its surface. These particles on reaching the plate are deposited there. Thus the smoke and other particles are removed from the gas coming out of chimney.

Electrostatic is also being used in applying paints on the surfaces of different articles. In automobile industry electro-painting has acquired the status of a standard technology (Fig. 15.11). The body of the car is earthed. When the particles of paint emerge out of the nozzle of the spray machine, they acquire a positive charge. When these positively charged particles reach near the body of the car, they induce negative charge on its surface due to electrostatic induction. These negative charges attract the incoming positively charged paint particles. Due to this force of attraction, a very firm coating of the paint is formed on the surface of the car. This method is very effective, efficient and cheap. It also requires less paint as compared to other methods. Hence it is being used to provide paint coating on refrigerators, metallic furniture and other articles.

15.9 CAPACITANCE

When we charge a conductor, some work has to be done during the process of transferring the charge to the conductor. This rises the potential of the conductor. Experiments show that the

charge Q on the conductor is directly proportional to its potential V , i.e.,

$$Q \propto V$$

or $Q = CV$ (15.8)

where C is a constant whose value depends upon the size of the conductor. It is known as capacitance of the conductor.

In Eq 15.8, if $V = 1$ volt, then $Q = C$ i.e., the capacitance of a conductor is equal to the amount of charge which raises the potential of the conductor by one volt. The unit of capacitance is known as farad. It is the capacity of that conductor whose potential rises by one volt when one coulomb charge is given to it.

Capacitor

Charge cannot be stored on a conductor for a long period of time because the stored charges mutually repel each other due to which they spread on the whole surface of the conductor and also tend to leak out from there. In order to store the charge for long periods, a device is used which is known as capacitor. It consists of two thin metal plates, parallel to each other with a very small distance between them. The medium between the two plates is air or a sheet of some insulator. This medium is known as dielectric. A plane parallel plate capacitor has been shown in Fig. 15.12.

If $+Q$ amount of charge is transferred to its plate A, due to electrostatic induction it would induce $-Q$ charge on the inner surface of the plate B and $+Q$ charge on its outer plate (Fig. 15.13). The lines of force between the plates have been shown.

There exists a force of attraction between the charges $+Q$ stored on the plate and the charge $-Q$ induced on the inner surface of plate B. Due to this force of attraction, the charges are bound with the plate and remain stored for long periods.

Due to presence of the charges on the plate, a potential difference V is created between them which is directly proportional to the charge Q given to the plate 'A'.

$$Q \propto V$$

Or $Q = CV$ (15.9)

Here C is the constant of proportionality, known as the capacitance of the capacitor.

Example 15.3: The capacitance of a parallel plate capacitor is 100 pF. If the potential difference between its plates is 50 volts, find

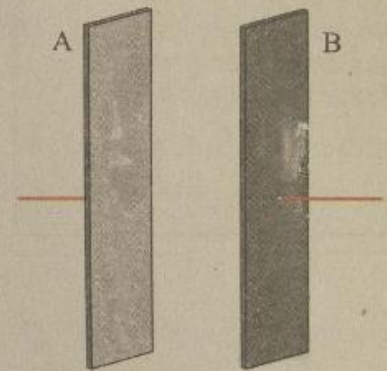


Fig. 15.12: Parallel plate capacitor

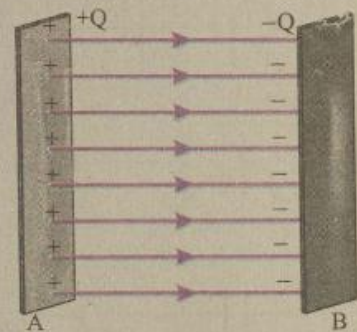


Fig. 15.13: The presence of charge of Q on plate A induces a $-Q$ charge on the inner surface of plate B.

Do you know?

Unit of capacitance has been named Farad after the name of an English scientist Micheal Faraday who discovered the law of electromagnetic induction.

Do you know?

Farad is a very big unit of capacitance. We generally use the following submultiples.

1 micro farad = $1\mu\text{F} = 1 \times 10^{-6} \text{ F}$

1 pico farad = $1\text{pF} = 1 \times 10^{-12} \text{ F}$

the quantity of charge on its plate.

Solution:

Potential difference between the plates = $V = 50\text{V}$

Capacitance = $C = 100\text{ pF}$

$$= 100 \times 10^{-12} \text{ F}$$

Charge = $Q = ?$

$$Q = CV$$

$$= 100 \times 10^{-12} \text{ F} \times 50\text{V}$$

$$= 5 \times 10^{-9} \text{ C} = 5 \text{ nC}$$

15.10 RULES FOR COMBINATION OF CAPACITORS

Quite a large number of capacitors are being used in various electronic circuits and very often they have to be connected together. Generally two methods are used for connecting them. One is known as parallel method and the other as series.

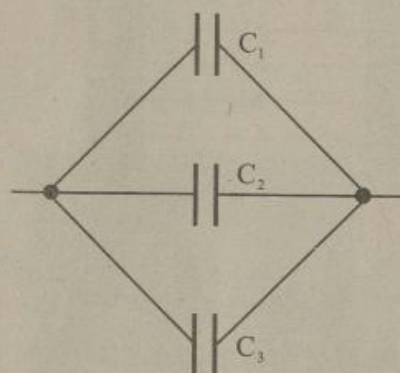


Fig. 15.14: Parallel connection of capacitors.

Parallel Combination of Capacitors

In this method left plates of all the capacitors are connected to one point and the right ones to another point (Fig. 15.14).

This type of combination has the following characteristic features:

(i) If this combination of capacitors, is connected with a battery of voltage V , the potential difference across each of the capacitors would be V . (Fig. 15.15)

(ii) The battery supplies charge to each capacitor, the quantity of which depends upon the capacitance of the capacitor. In the circuit shown in Fig. 15.15, the charge on capacitor C_1 is $Q_1 = C_1 V$, the charge on capacitor C_2 is $Q_2 = C_2 V$ and that on C_3 is $Q_3 = C_3 V$. If Q is the total charge supplied by the battery, then

$$\begin{aligned} Q &= Q_1 + Q_2 + Q_3 \\ &= C_1 V + C_2 V + C_3 V \\ &= (C_1 + C_2 + C_3) V \end{aligned} \quad \dots\dots\dots (15.10)$$

$$\frac{Q}{V} = C_1 + C_2 + C_3$$

(iii) The parallel combination of capacitors, in a circuit, can be replaced by its equivalent capacitor of capacitance C , such that

$$C = C_1 + C_2 + C_3$$

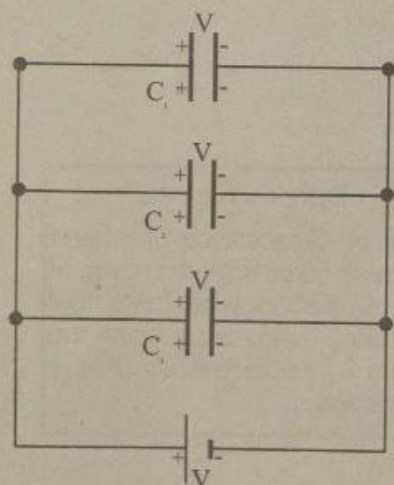


Fig. 15.15: Potential difference across every capacitor is equal to the voltage of the battery.

If n capacitors are combined in parallel, the equivalent capacitance of the combination is given by

$$C_e = C_1 + C_2 + C_3 + \dots + C_n \quad \dots\dots (15.11)$$

Generally capacitors are connected in parallel to increase the value of capacitance.

Series Combination of Capacitors

In this method the capacitors are connected plate to plate, i.e., the right plate of one capacitor is connected to the left plate of the next capacitor as shown in Fig. 15.16.

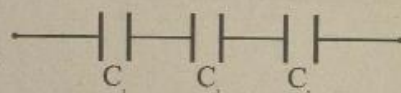


Fig. 15.16: Series connection of capacitors.

The following are the characteristic features of this combination:

(i) If this combination is connected to a battery, the charge on each capacitor would be the same. (Fig. 15.17). The battery supplies $+Q$ charge to the left plate of the capacitor C_1 . Due to induction, $-Q$ charge is induced on its right plate and $+Q$ charge on the left plate of the capacitor C_2 . This process continues as a result of which each capacitor has Q charge.

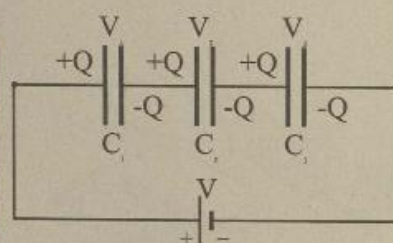


Fig. 15.17: Amount of charge is same on each capacitor.

(ii) The potential difference between the plates of each capacitor is according to its capacitance. In the circuit shown in Fig. 15.17, the potential difference between the plates of capacitor C_1 is $V_1 = Q/C_1$, the potential difference across the plates of capacitor C_2 is $V_2 = Q/C_2$ and that across C_3 is $V_3 = Q/C_3$. It is the voltage V of the battery that is divided among the various capacitors. Hence

$$\begin{aligned} V &= V_1 + V_2 + V_3 \\ &= \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} \\ &= Q \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) \end{aligned}$$

(iii) The series combination of capacitors in a circuit can be replaced by its equivalent capacitance C_e , the value of which is given by

$$\frac{1}{C_e} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right)$$

If n capacitors are connected in series, the equivalent capacitance of the combination is given by

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots + \frac{1}{C_n} \quad \dots\dots (15.12)$$

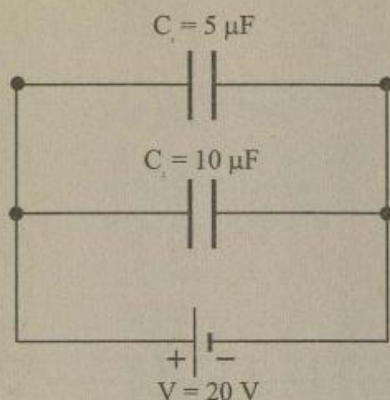


Fig. 15.18

Example 15.4: Two capacitors of $5 \mu\text{F}$ and $10 \mu\text{F}$ capacitance are connected in parallel. What would be the equivalent capacity? If a 20V battery is connected across the combination (Fig. 15.18), find out

- (i) the voltage across the two capacitors.
- (ii) the quantity of charge on each capacitor.

Solution:

$$C_1 = 5 \mu\text{F} = 5 \times 10^{-6} \text{ F}$$

$$C_2 = 10 \mu\text{F} = 10 \times 10^{-6} \text{ F}$$

If C_e is the equivalent capacitance of this parallel combination,

$$\begin{aligned} C_e &= C_1 + C_2 \\ &= 5 \mu\text{F} + 10 \mu\text{F} = 15 \mu\text{F} \end{aligned}$$

(i) As the two capacitors are connected in parallel, the voltage drop across each capacitor would be the same, equal to voltage of the battery i.e., 20 volts .

(ii) Let the charge on the capacitor of capacitance $C_1 = Q_1 = ?$

$$\text{Capacitance} = C_1 = 5 \mu\text{F} = 5 \times 10^{-6} \text{ F}$$

$$\text{Voltage} = V = 20\text{V}$$

Since

$$Q_1 = C_1 V$$

So

$$\begin{aligned} &= 5 \times 10^{-6} \text{ F} \times 20\text{V} \\ &= 100 \times 10^{-6} \text{ FV} = 100 \mu\text{C} \end{aligned}$$

Let the charge on the capacitor of capacitance $C_2 = Q_2 = ?$

So

$$\begin{aligned} Q_2 &= C_2 V \\ &= 10 \times 10^{-6} \text{ F} \times 20\text{V} \\ &= 200 \mu\text{C} \end{aligned}$$

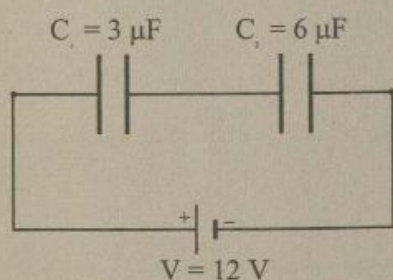


Fig. 15.19

Example 15.5: Capacitors of $3 \mu\text{F}$ and $6 \mu\text{F}$ capacitance are connected in series. Find the equivalent capacitance (Fig. 15.19).

Solution:

$$C_1 = 3 \mu\text{F} = 3 \times 10^{-6} \text{ F}$$

$$C_2 = 6 \mu\text{F} = 6 \times 10^{-6} \text{ F}$$

If C_e is the equivalent capacitance of the series combination, it is given by

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{C_1 + C_2}{C_1 C_2}$$

$$C_e = \frac{C_1 C_2}{C_1 + C_2}$$

$$= \frac{3 \times 10^{-6} \text{ F} \times 6 \times 10^{-6} \text{ F}}{3 \times 10^{-6} \text{ F} + 6 \times 10^{-6} \text{ F}} = 2 \times 10^{-6} \text{ F} = 2 \mu\text{F}$$

15.11 DIFFERENT TYPES OF CAPACITORS

Capacitors have been classified into various types depending upon their construction and the nature of dielectric used in them. If the capacitor is such that its plates are immovable, it is known as a fixed capacitor. Its value does not change. Paper capacitor is an example of fixed capacitors. The paper capacitor is cylindrical in shape. Generally an oiled or greased paper or a thin plastic sheet is used as a dielectric between two aluminium foils which is firmly rolled in the form of a cylinder and is then enclosed into a plastic case (Fig. 15.20).

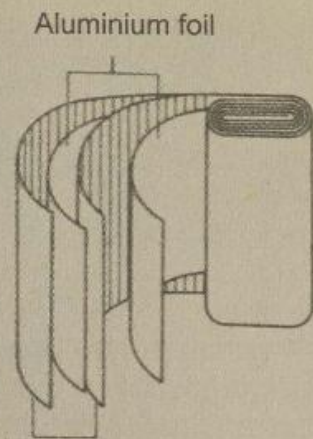
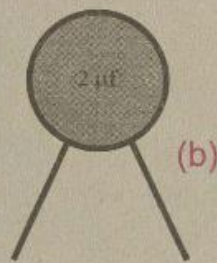
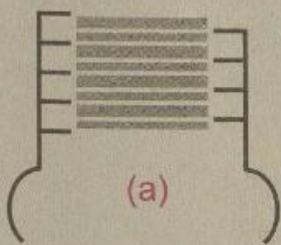


Fig. 15.20(a)

Mica capacitor is another example of fixed capacitors. In these capacitors, mica is used as dielectric between two metal plates. For convenience and safety it is enclosed in a plastic case or in a case of some insulator. Wires attached with plates project out of the case for making connections. If the capacitance is to be increased, a large number of plates are piled up, one over the other with layers of dielectric in between and alternate plates are connected with each other (Fig. 15.21).



Mica capacitor
Fig. 15.21

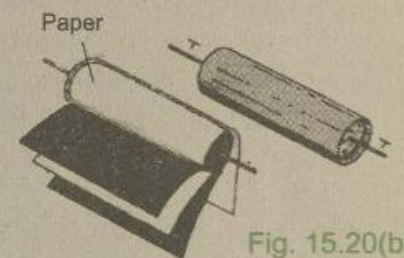


Fig. 15.20(b)

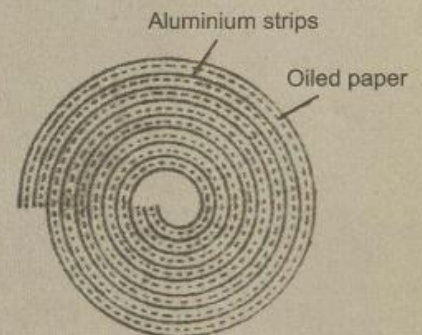


Fig. 15.20(c)

Paper capacitor

If in a parallel plate capacitor some arrangement is made so that the area of the plates facing each other can be changed, then it is called a variable capacitor. It is usually a combination of many capacitors with air as dielectric. It consists of two sets of plates. One set remains static while the second one can rotate so the distance between the plates remains the same and they do not touch each other. The common area of the plates of the two sets which faces each other, determines the value of the capacitance. Thus the capacitance of the capacitor can be increased or decreased by turning the rotatable plates in or out of the space between the static plates (Fig. 15.22). Such capacitors are generally used for tuning in radio sets.



Fig. 15.22

Variable capacitor

SUMMARY

1. Electric charges are of two types, positive charge and a negative charge. Like charges repel and unlike charges attract each other.

2. The phenomenon in which a charged body produces an opposite charge at one end and a like charge at the other end of an insulated conductor is known as electrostatic induction.

3. The force of attraction or repulsion between two charged bodies is given by Coulomb's law which is stated as "The force between two charged bodies is directly proportional to the product of the charges and inversely proportional to the distance between them."

Mathematically it is written as

$$F = \frac{1}{4\pi\epsilon_0} \times \frac{q_1 q_2}{r^2}$$

4. Electric field of a charge is the region of space surrounding it in which a point charge can experience its influence in the form of a force.

5. A charge is also surrounded by the field of electric potential. The potential at any point in the field is defined as the potential energy of a unit positive charge placed at that point. Volt is the unit of potential. If the potential energy of one coulomb positive charge placed at a point is one joule, its potential is one volt.

6. Capacitor is a device which stores electric charge.

7. There are two methods to connect capacitors. One is known as parallel combination and the other as series combination.

(i) The equivalent capacitance C_e of a parallel combination of n capacitors is given by their sum.

$$C_e = C_1 + C_2 + C_3 + \dots + C_n$$

(ii) The equivalent capacitance C_e of a series combination of n capacitors is given by the sum of their reciprocals

$$\frac{1}{C_e} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots + \frac{1}{C_n}$$

QUESTIONS

15.1 Show by experiments that electric charges are of two kinds.

15.2 Why is electric charge produced in bodies by friction?

15.3 Explain the phenomenon of electrostatic induction. How is an insulated conductor charged by electrostatic induction?

15.4 Describe a gold leaf electroscope. By using an electroscope, how can we find the

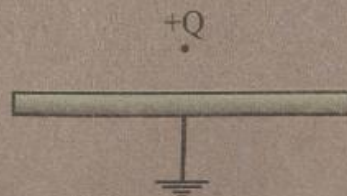
- (i) presence of charge on a body.
- (ii) the nature of the charge present on a body.
- (iii) whether a body is insulator or a conductor.

15.5 Explain Coulomb's law and write it in the mathematical form.

15.6 What is meant by electric field and electric intensity? Find the electric intensity due to a point charge Q .

15.7 What is meant by electric lines of force? Explain.

15.8 A point charge $+Q$ is placed in front of a plane metallic plate as shown in the figure. Draw the lines of force.



15.9 What is meant by electric potential? Explain.

- 15.10** Define potential difference between two points.
- 15.11** What is meant by the capacitance of a conductor? Explain.
- 15.12** Describe a capacitor. How does it store charge?
- 15.13** How are the capacitors connected in parallel? Describe the characteristic features of this combination.
- 15.14** How are the capacitors connected in series? Describe the characteristic feature of this combination.
- 15.15** Four answers have been given to each of the following questions. Tick (✓) the correct one.
- (i) The distance between two point charges is 20 cm. If the distance is

reduced to 10 cm, the Coulomb's force would become

- (a) half (b) two times
(c) one fourth (d) four times

- (ii) When a positive charge of 2 coulombs is placed at a point in an electric field, it experiences a force of 6 N. The intensity of electric field at this point is
- (a) 6 NC (b) 3 NC
(c) 12 NC (d) 1.5 NC
- (iii) The instrument which stores charge is known as
- (a) electroscope (b) conductor
(c) capacitor (d) capacitance

NUMERICAL PROBLEMS

- 15.1** The charge of how many electrons would be equal to $10 \mu\text{C}$?
(6.25×10^{11})
- 15.2** Two point charges $q_1 = 10 \mu\text{C}$ and $q_2 = 5 \mu\text{C}$ are placed at a distance of 150 cm. Find the Coulomb's force between them. What is the direction of this force?
(0.2N, the direction of repulsion)
- 15.3** When a charge of $+10 \mu\text{C}$ is placed at a point, it experiences a force of 10^{-3} N. Find the value of electric intensity at this point.
(10 NC^{-1})
- 15.4** The value of a point charge is $500 \mu\text{C}$. Find the electric intensity due to it at a distant of 50 cm from it.
($1.8 \times 10^3 \text{ NC}^{-1}$)
- 15.5** The potential at a point in an electric field is 10 V. If a charge of $+100 \mu\text{C}$ is brought from infinity to this point. What would be the amount of work done on it?
(1 J)
- 15.6** The potential at a point in an electric field is 100 V. If a charge of $750 \mu\text{C}$ is placed at this point, what would be its potential energy?
(0.075 J)
- 15.7** A point charge of $+2\text{C}$ is transferred from a point at potential 100 V to a point at potential 50V, what would be the energy supplied by the charge?
(100 J)
- 15.8** The capacitance of a parallel plate capacitor is 50 pF. If this capacitor is charged by a battery of 12 V, what would be the charge stored in the capacitor?
(0.6 nC)
- 15.9** Two capacitors of capacitance $5 \mu\text{F}$ and $10 \mu\text{F}$ are connected in parallel. Find the equivalent capacitance of the combination. If a battery of 10 V is connected across this combination, find the charge stored in each capacitor.
($15 \mu\text{F}$, $50 \mu\text{C}$, $100 \mu\text{C}$)
- 15.10** Two capacitors of capacitance $6 \mu\text{F}$ and $12 \mu\text{F}$ are connected in series. Find the equivalent capacitance of the combination. If a 12V battery is connected across this combination. Find the charge and the potential difference across each capacitor.
($4 \mu\text{F}$, $48 \mu\text{C}$, 8 V, 4 V)

CURRENT ELECTRICITY

In this chapter you will learn:

1. Electric current.
2. Potential difference and electromotive force.
3. Ohm's law.
4. Resistance.
5. Measuring instruments.
6. Electric energy and Joule's law.
7. Alternating and direct current.
8. Electricity hazards and safety measures.

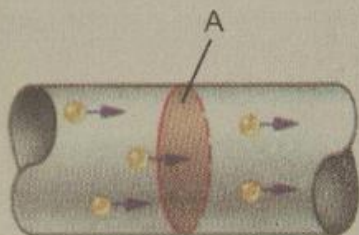


Fig. 16.1

16.1 ELECTRIC CURRENT

We have been considering charges at rest till now. Now we will learn about the charges in motion. When electric charges are moving across any surface then we say that an electric current is flowing through that surface.

Electric charges are of two kinds, positive and negative. So, electric current is produced due to the flow of negative charge or positive charge or both kinds of charges. In metals, the current is produced only due to the flow of free electrons i.e., negative charge. In case of electrolyte its molecules are dissociated among positive and negative ions in solution. Thus the current in electrolyte is due to flow of both the positive and negative charges.

The rate of flow of electric charge through any cross-sectional area is called electric current. If the charge Q is passing through an area A in time t second (Fig. 16.1), then the current flowing through it will be I , whereas

$$I = \frac{Q}{t} \quad \text{.....} \quad (16.1)$$

In system International, the unit of current is known as ampere.

Conventional Current

Suppose a stream of positively charged particles is injecting in a metal cup (Fig. 16.2). We will say that an electric current is flowing through the upper cross-section of the cup. As due to this current the amount of positive charge is increasing in the cup, so electric current is flowing into the cup. This current is due to motion of positive charges and its direction is the same as that of the motion of positive charges. If we now stop injecting positive charges and instead start injecting a beam of electrons into the cup, then the quantity of positive charges stored in the cup would start

Do You Know?



The current through the filament of a bulb is only due to flow of negative charge i.e., free electrons.

neutralizing due to which the quantity of charge in the cup would decrease and it would so seem to us that a current of positive charge is flowing out of the cup. Thus the effect of flow of current due to negative charge is the same as that of the current due to an equal amount of positive charge flowing in opposite direction. As electric current is measured by the effect which it produces, therefore we can say that a current produced due to flow of negative charges is equivalent to a current due to flow of an equal amount of positive charge in opposite direction. This equivalent current of positive charge is known as conventional current. Whenever current flows due to motion of negative charges, it is substituted by its equivalent positive charge conventional current flowing in opposite direction and we can assume that electric current is always due to flow of positive charges.

Now let us see how a current flows in a conductor. Consider a conductor in form of a copper wire. It has a large number of free electrons which are in random motion just like the molecules of a gas confined in a container. Their movement does not obey any symmetry but they move in all directions (Fig. 16.3). In absence of an electric field the rate at which the free electrons cross any section of the wire from right to left is equal to the rate at which they cross from left to right with the result that the net rate is zero. So in spite of the fact that electrons are in motion, no current flows through any section of the conductor. Now if one end of the copper wire is connected with the positive terminal of a battery and the other with its negative terminal, an electric field E is established at each point of the wire (Fig. 16.3-a). Now the free electrons, because of their negative charge, experience a force in a direction opposite to the direction of electric field E . Because of this force a net directed flow of free electrons takes place from the negative terminal of the battery towards its positive terminal and an electric current begins to flow through the wire from the positive terminal towards the negative terminal of the battery. Note the current flow due to negative charges has been changed with conventional current. This current flows in the wire from positive to negative terminal of the battery i.e., current flows from a point of higher potential to a point of lower potential.

Example 16.1: If 0.5C charge passes through a certain surface in 10s, then find the current flowing through this surface.

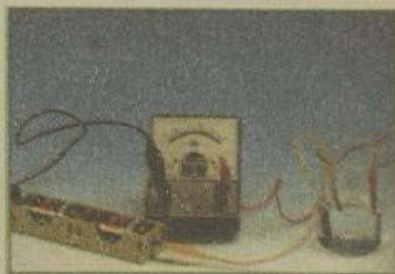
Solution:

$$Q = 0.5 \text{ C} \quad , \quad t = 10 \text{ s}$$

$$I = \frac{Q}{t} = \frac{0.5 \text{ C}}{10 \text{ s}} = 0.05 \text{ A}$$

$$= 50 \text{ mA}$$

For Your Information



The flow of current through an electrolyte is due to motion of both the positive and negative charges.

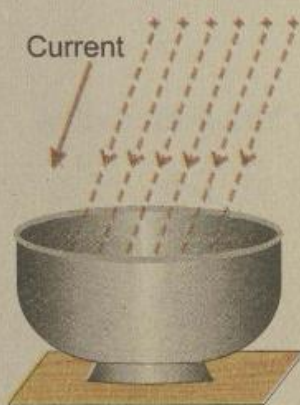


Fig. 16.2



Fig. 16.3

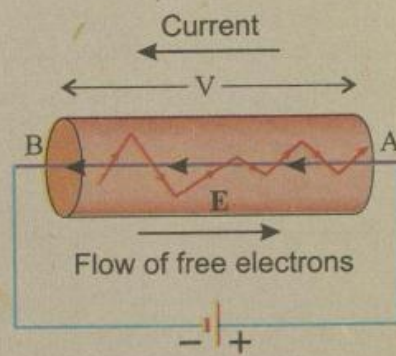


Fig. 16.3 (a)

16.2 POTENTIAL DIFFERENCE AND emf

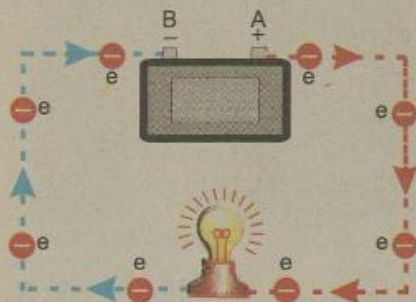
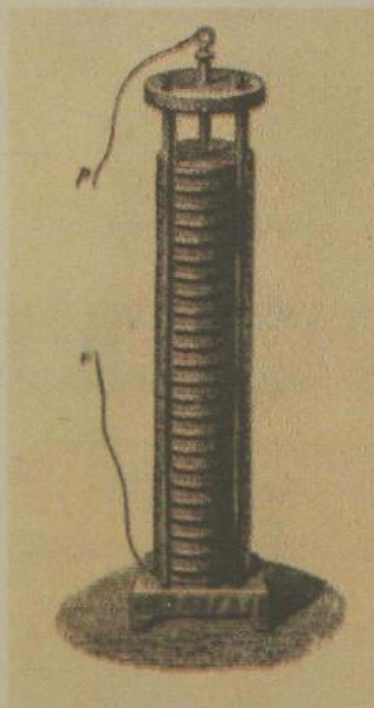


Fig. 16.4

When one end A of the conductor is connected to the positive terminal and its other end B is connected to the negative terminal of the battery, then the potential of A becomes higher than the potential of B. An electric field is setup due to which the current flows from A to B. This flow of current is due to the motion of free electrons from B to A.

For continuous flow of current, it is essential that when the electrons after passing through the conductor reach the positive terminal A of the battery, they should be pumped from this to the negative terminal B through the battery (Fig. 16.4). This transfer of electrons in the battery takes place due to a chemical process which produce the necessary energy for pumping the electrons. The amount of energy supplied by the battery in pushing one coulomb of charge (electrons) from its positive terminal to its negative terminal through the battery is known as the electromotive force.

For You Information



The first battery was made in 1800. It consisted of copper and zinc plates which were soaked in salt water. This was the first source of

When a conductor is connected across the terminals of the battery, electrons begin to flow through it. During their flow, they face a resistance due to the collisions with the atoms present in the conductor. The energy supplied to electrons by the battery is utilised in overcoming this resistance and is dissipated as heat and other forms of energy. The dissipation of this energy is accounted for by the potential difference across the two ends of the conductor. Thus the emf gives the energy supplied to unit charge by the battery and the potential difference accounts for the dissipation of this energy into other forms as unit charge passes through the circuit.

16.3 OHM'S LAW

If V is the potential difference across the ends of any conductor, then current I will flow through it. The value of the current changes with changes in potential difference. German scientist Simon Ohm found out that.

The value of current I passing through a conductor is directly proportional to the potential difference V applied across its ends, provided the temperature and the physical state of the conductor does not change.

If a graph is drawn between V and I , it will be a straight line (Fig. 16.5) which represents the directly proportional relation between V and I i.e.,

$$V \propto I$$

or $V = IR$ (16.2)

where R is the constant of proportionality whose value can be determined from V - I graph. The value of R is different for different conductors.

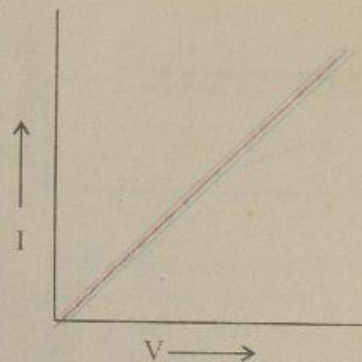


Fig. 16.5

Limitations of Ohm's Law

Ohm's law is applicable only in conductors even when its temperature and physical state does not change. It is applicable only in metallic conductors.

16.4 RESISTANCE

The property of a substance which opposes the flow of current through it is called its resistance. In Eq. 16.2, it can be seen that for a certain value of potential V , if the value of R is increased, then the current I would be small. It means the opposition to current is large. On the other hand, if R is small, the current would be large which means that the opposition to flow of current is small. Thus the proportionality constant R in Eq. 16.2 is a measure of the resistance of the conductor. Its value can be determined by the V - I graph.

The unit used to measure the resistance is called ohm. In Eq. 16.2, if $V = 1$ volt and $I = 1$ ampere, the value of R would be 1 ohm. Thus a conductor would have a resistance of one ohm, if a current of one ampere passes through it when a potential difference of one volt is applied across its ends. Ohm is usually represented by the Greek letter.

Example 16.2: The potential difference across an electric bulb is 220 V. If the current passing through it is 440 mA, then find the resistance of the bulb. If the potential difference is increased to 250 V, what would be the value of current?

Solution:

$$\text{Potential difference} = V = 220 \text{ V}$$

$$\text{Current} = I = 440 \text{ mA} = 440 \times 10^{-3} \text{ A}$$

$$\text{Resistance} = R = ?$$

For Your Information

- 1 Mega Ohm = $1 \text{ M}\Omega = 1 \times 10^6 \Omega$
- 1 Kilo Ohm = $1 \text{ k}\Omega = 1 \times 10^3 \Omega$
- 1 Milli Ohm = $1 \text{ m}\Omega = 1 \times 10^{-3} \Omega$
- 1 Micro Ohm = $1 \mu\Omega = 1 \times 10^{-6} \Omega$

For Your Information

- $1 \text{ mA} = 10^{-3} \text{ A}$
- $1 \mu\text{A} = 10^{-6} \text{ A}$

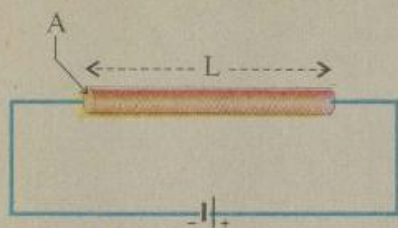


Fig. 16.6: The resistance R of any wire is inversely proportional to its area A and is directly proportional to its length L .

By Ohm's law

$$R = \frac{V}{I} = \frac{220 \text{ V}}{440 \times 10^{-3} \text{ A}} \\ = 500 \Omega$$

Now if $V = 250 \text{ V}$. By Ohm's law

$$I = \frac{V}{R} = \frac{250 \text{ V}}{500 \Omega} = 0.5 \text{ A} \\ = 500 \text{ mA}$$

Specific Resistance

At a certain temperature the resistance of a conducting wire depends upon its length, area of cross-section and the nature of the material of the wire. By measuring the resistance of wires of different length and different area of cross-section, it was found that:

Table 16.1

Metal	Specific resistance ($10^{-8} \Omega \text{ m}$)
Silver	1.62
Copper	1.69
Aluminium	2.75
Tungsten	5.25
Platinum	10.6

(i) The resistance R of the wire is directly proportional to its length L . Mathematically

$$R \propto L$$

It means if the length of wire is doubled, its resistance will also be doubled and if its length is halved, then its resistance would become one half.

(ii) The resistance R of the wire is inversely proportional to the area of cross-section A of the wire i.e.,

$$R \propto \frac{1}{A}$$

It means that a thick wire would have smaller resistance than a thin wire.

After combining the two ratios

$$R \propto \frac{L}{A}$$

$$R = \rho \frac{L}{A} \quad \dots\dots\dots (16.3)$$

where ρ is the constant of proportionality, known as specific resistance. Its value depends upon the nature of conductor i.e., copper, iron, tin and silver would each have a different values of ρ .

If in Eq. 16.3, if $L = 1 \text{ m}$ and $A = 1 \text{ m}^2$ then $R = \rho$ i.e., the resistance of one metre cube of a substance is equal to its specific resistance. According to Eq. 16.3 the unit of ρ is ohm-metre ($\Omega \text{ m}$). The specific resistance of some metals is given in Table 16.1.

Example 16.3: Length of a copper wire is 1 metre and its diameter is 2 mm. Find its resistance.

Solution:

Length of the wire = $L = 1\text{m}$

Diameter of the wire = $d = 2\text{ mm} = 2 \times 10^{-3}\text{m}$

$$\begin{aligned}\text{Cross-sectional area} = A &= \frac{\pi d^2}{4} = \frac{3.14 \times (2 \times 10^{-3})^2 \text{ m}^2}{4} \\ &= 3.14 \times 10^{-6} \text{ m}^2\end{aligned}$$

Specific resistance of copper = $\rho = 1.69 \times 10^{-8} \text{ m}$

As
$$R = \rho \times \frac{L}{A}$$

Therefore,
$$\begin{aligned}R &= 1.69 \times 10^{-8} \Omega \text{ m} \times \frac{1\text{m}}{3.14 \times 10^{-6} \text{ m}^2} \\ &= 0.54 \times 10^{-2} \Omega \\ &= 5.4 \text{ m}\Omega\end{aligned}$$

Effect of Temperature upon Resistance

Usually a metallic conductor has a crystalline structure in which its various atoms in form of positive ions are fixed at their respective places as shown in Fig. 16.7. Free electrons move in the space between these atoms. During the course of their motion, they continuously collide with the atoms. After collision they scatter in various directions. When we apply a potential across the ends of the conductor, the free electrons, in addition to their random motion, have a directed motion with a velocity known as drift velocity. The current flows through the conductor due to this velocity. The opposition to flow of current is caused by the collision of free electrons with the atoms of the conductor because after each collision the direction of motion of the electron randomly changes which slows down the drift velocity. More frequently electrons collide with the atoms, the larger is opposition or resistance in the flow of current. When the temperature of the conductor rises, average speed of the random motion of the free electrons increases which enhances the rate of collision of electrons and the atoms. This causes an increase in the resistance of the conductor. The increase in resistance is directly proportional to the increase of temperature. If R_0 is the resistance at 0°C and R_t at $t^\circ\text{C}$, then we can write as



Fig. 16.7

$$\begin{aligned}R_t - R_0 &\propto R_0 \times t \\ R_t - R_0 &= \alpha R_0 \times t \quad \dots\dots\dots (16.4)\end{aligned}$$

Here α is a constant which is the rate of increase in resistance per ohm per Kelvin.

Hence by taking measurements of the resistance of a conductor at different temperatures, it is possible to measure the temperature. This is the principle on which a resistance thermometer works.

Resistance Thermometer

The conductor used in resistance thermometer is usually a platinum wire whose ends are welded with thick copper wire (Fig. 16.8). Before measuring the temperature of a substance, the thermometer is placed in melting ice and its resistance at 0°C is measured. Let it be R_0 ohm. Then the bulb of the thermometer is placed into the substance whose temperature is to be measured. The resistance of the platinum wire is again measured. Let this time its value is R_t ohm. According to Eq. 16.4.

$$t = \frac{R_t - R_0}{R_0 \times \alpha}$$

In this equation α is the rate of increase in the resistance of platinum per ohm per Kelvin rise of temperature. Its value is $3.9 \times 10^{-3}/^\circ\text{C}$. Temperatures from -260°C to 630°C can be measured by a platinum resistance thermometer.

Series and Parallel Combination of Resistances

There are two basic methods by which resistances are connected in a circuit. One method is known as series combination and the other as parallel combination.

(a) Series combination of Resistances

(i) In this method resistances are connected end to end and the circuit thus formed provides only one path for the flow of current (Fig. 16.9).

(ii) In this arrangement, the magnitude of current that flows through each individual resistor is the same.

(iii) In series combination, the sum of voltages across each of the resistors is equal to the voltage of the battery connected across the combination. In Fig. 16.9, if the voltage of the battery is V and V_1 , V_2 , V_3 are the voltages across the resistors R_1 , R_2 , R_3 respectively, then

$$V = V_1 + V_2 + V_3$$

If the current passing through the resistors R_1 , R_2 , R_3 is I , then

$$V = IR_1 + IR_2 + IR_3$$

$$V = I(R_1 + R_2 + R_3) \quad \dots\dots\dots (16.5)$$

(iv) The equivalent resistance R_e of a series combination is that resistance which when substituted in place of the combination, the same current would flow through the circuit. Fig. 16.10 shows the equivalent resistance R_e . Note that the battery is sending the same current, which it was sending when the combination was connected in the circuit. By Ohm's law,

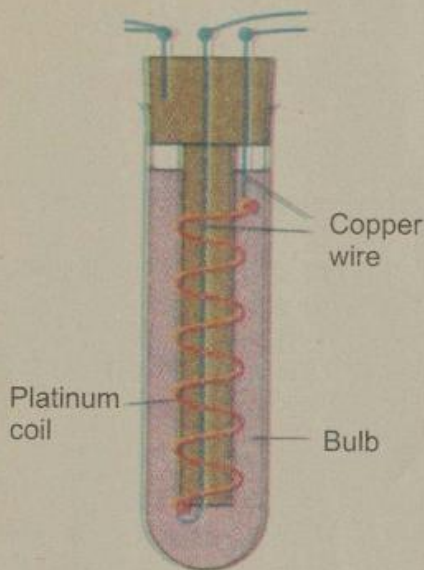


Fig. 16.8: A platinum resistance thermometer

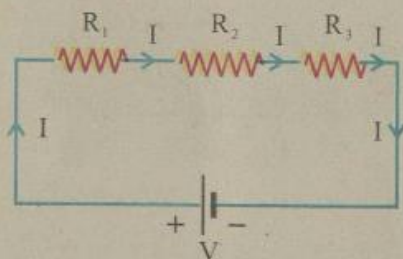


Fig. 16.9

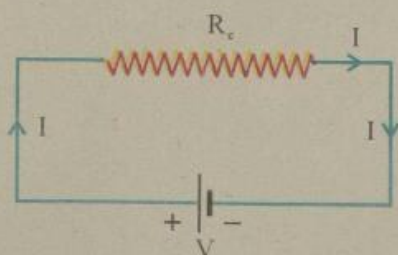


Fig. 16.10

$$V = IR_e \quad \dots\dots\dots (16.6)$$

By substituting the value of V in Eq. 16.5

$$IR_e = I(R_1 + R_2 + R_3)$$

or $R_e = R_1 + R_2 + R_3 \quad \dots\dots\dots (16.7)$

Thus the equivalent resistance of a series combination is equal to the sum of the individual resistances of the combination.

If resistances $R_1, R_2, R_3, \dots, R_n$ are connected in series then their equivalent resistance R_e can be determined by the following equation.

$$R_e = R_1 + R_2 + R_3 + \dots + R_n \quad \dots\dots\dots (16.8)$$

Example 16.4: In Fig. 16.9, if the value of resistors R_1 and R_2 is $6\text{ k}\Omega$ and $4\text{ k}\Omega$ respectively and the voltage of battery is 10 V , then find the following quantities.

- (i) Equivalent resistance of the series combination.
- (ii) The current flowing through each of the resistance.
- (iii) Potential difference across each of the resistances.

Solution:

(i) $R_1 = 6\text{ k}\Omega, R_2 = 4\text{ k}\Omega$

If R_e is the equivalent resistance of this series combination,

$$\begin{aligned} R_e &= R_1 + R_2 \\ &= 6\text{ k}\Omega + 4\text{ k}\Omega = 10\text{ k}\Omega \end{aligned}$$

- (ii) If a battery of 10 V is connected across the equivalent resistance, the current passing through it is given by

$$I = \frac{V}{R_e} = \frac{10\text{ V}}{10\text{ k}\Omega} = 10^{-3}\text{ A}$$

According to definition of equivalent resistance same current would pass through each resistance of the series combination.

(iii) Potential difference across $R_1 = V_1 = IR_1$
 $= 10^{-3}\text{ A} \times 6\text{ k}\Omega = 6\text{ V}$

Potential difference across $R_2 = V_2 = IR_2$
 $= 10^{-3}\text{ A} \times 4\text{ k}\Omega = 4\text{ V}$

Do you know??



Resistances of different values are important component of electronic circuits.

(b) Parallel Combination of Resistances

In this combination, resistances are connected in such a way that one end of all the resistors is connected to one point, say 'A' and all the other ends to another point 'B' as shown in Fig. 16.11 (a). In the circuit thus formed, several paths are available for the flow of current. The total current of the circuit is divided in these paths. The parallel combination has the following characteristic features.

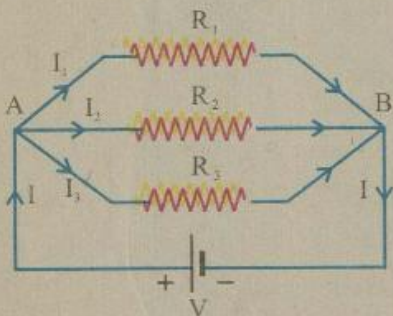


Fig. 16.11(a)

(i) In this combination, the potential drop across all the resistances is the same. In Fig. 16.11 (a) the potential drop across each of the resistance will be V .

(ii) The sum of the current flowing through the various resistances of this combination is equal to the total current of the circuit. In Fig. 16.11 (a)

$$I = I_1 + I_2 + I_3 \quad \dots\dots\dots (16.9)$$

As the potential drop across each resistance is V so by Ohm's law

$$I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2} \quad \text{and} \quad I_3 = \frac{V}{R_3}$$

After substituting the values of I_1 , I_2 and I_3 in Eq. 16.9,

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = V \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right) \quad \dots\dots\dots (16.10)$$

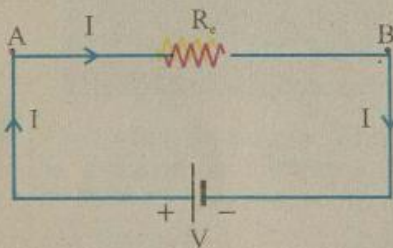


Fig. 16.11(b)

(iii) The equivalent resistance R_e of the parallel combination is that resistance which when substituted in place of the parallel combination does not alter the total current of the circuit (Fig. 16.11-b).

By Ohm's law
$$I = \frac{V}{R_e}$$

By putting the value of I in Eq. 16.10,

$$\frac{V}{R_e} = V \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \right)$$

or
$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \quad \dots\dots\dots (16.11)$$

If resistances $R_1, R_2, R_3, \dots, R_n$ are connected in parallel, then their equivalent resistance can be determined by the following equation.

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n} \quad \dots (16.12)$$

Example 16.5: If in the circuit shown in Fig. 16.11, $R_1 = 2\Omega$, $R_2 = 3\Omega$, $R_3 = 6\Omega$ and $V = 6V$, then find the following quantities:

- (i) equivalent resistance of the circuit.
- (ii) current flowing through each of the resistance.
- (iii) the total current of the circuit.

Solution:

If R_e is the equivalent resistance of the parallel combination, then

$$\begin{aligned} \frac{1}{R_e} &= \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \\ \frac{1}{R_e} &= \frac{1}{2\Omega} + \frac{1}{3\Omega} + \frac{1}{6\Omega} = \frac{6}{6\Omega} \\ R_e &= 1\Omega \end{aligned}$$

Note that the value of the equivalent resistance of the parallel combination is smaller than the lowest value of the resistance used in this combination.

(ii) As the resistances are connected in parallel, so the potential difference across each of the resistance would be equal and its value will be equal to the potential $V = 6V$ of the battery.

$$\text{Current passing through } R_1 = I_1 = \frac{V}{R_1} = \frac{6V}{2\Omega} = 3A$$

$$\text{Current passing through } R_2 = I_2 = \frac{V}{R_2} = \frac{6V}{3\Omega} = 2A$$

$$\text{Current passing through } R_3 = I_3 = \frac{V}{R_3} = \frac{6V}{6\Omega} = 1A$$

As the sum of the current passing through the resistances of parallel combination is equal to the total current I of the circuit. Therefore

$$\begin{aligned} I &= I_1 + I_2 + I_3 \\ &= 3A + 2A + 1A = 6A \end{aligned}$$

16.5 MEASURING INSTRUMENTS

(i) Galvanometer

Galvanometer is a very sensitive instrument by which we can detect the presence of current in a circuit. Apparently it consists of a dial on which a needle can rotate (Fig. 16.12). In order to detect current in a circuit, the galvanometer is connected in the



A galvanometer
Fig. 16.12

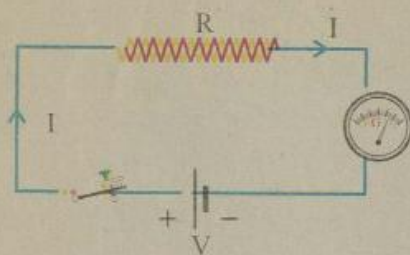


Fig. 16.13

circuit in series (Fig. 16.13). If its needle shows some deflection, it would indicate the presence of current in the circuit.

Galvanometer is also used to indicate potential difference between two points of a circuit. Fig. 16.14 shown as electrical circuit. If we have to find whether its points A and B are at the same potential or not, a galvanometer is connected between these points (Fig. 16.14). If the galvanometer shows a deflection, it would indicate that a current is passing through the galvanometer. This would happen only in the case when there is a potential difference between the points A and B. If the galvanometer shows no deflection the points A and B would be at the same potential.

(ii) Ammeter

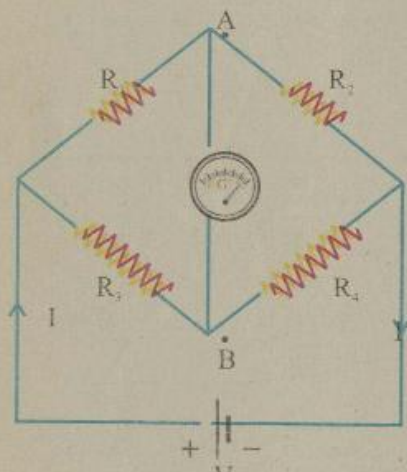


Fig. 16.14

Galvanometer is a very sensitive instrument. Only a current of few milli-ampere is sufficient to cause full scale deflection in it. Therefore it can not be used directly to measure current because usually during experiments, current in a circuit is quite large. After suitable modification, a galvanometer is used to measure large values of current. This modification is accomplished by connecting a suitable low resistance in parallel with the galvanometer (Fig. 16.15). This resistance is known as shunt. Shunt provides an alternate path for the current to flow. The major part of the total current passes through the shunt and a small fraction of it flows through the galvanometer. In this way the range of the galvanometer for current measurement is considerably increased. This modified galvanometer is known as ammeter. Usually the resistance of the shunt is very small. As in ammeter it is connected in parallel with the galvanometer, hence the resistance of an ammeter is very low.



Fig. 16.15

In order to measure current in a circuit, the ammeter is connected in series, so the current flowing in the circuit also passes through the ammeter (Fig. 16.16). As the resistance of the ammeter is very small, so its introduction into the circuit does not affect the current of the circuit.

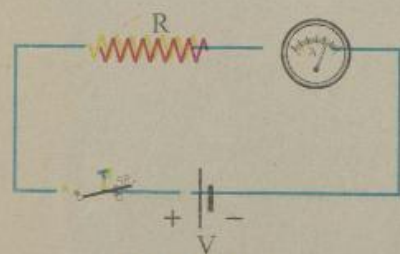


Fig. 16.16

Before connecting an ammeter in the circuit, one should see that the current to be measured lies within the range of the ammeter. Usually the needle of the ammeter moves only in one direction. If it is made to move in opposite direction it is likely to be damaged. Therefore when an ammeter is connected in a circuit, this precaution should be observed that the current enters the ammeter through its terminal marked positive (+).

(iii) Voltmeter

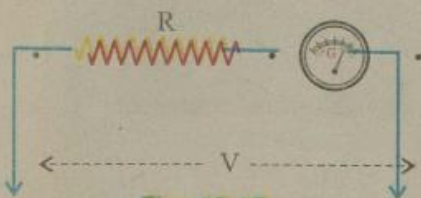


Fig. 16.17

When current I passes through a resistance R , there would be a potential across its two ends the value of which is equal to $V = IR$. This potential difference can be directly measured by an instrument known as voltmeter. Galvanometer is converted into a voltmeter by connecting a suitable resistance in series with it

(Fig. 16.17). The value of this series resistance depends upon the range of the voltmeter. Usually its value is several thousand ohms. Thus the resistance of a voltmeter is very high.

Voltmeter is always connected in parallel with the resistance across which the potential difference is to be measured (Fig. 16.18). Higher the resistance of the voltmeter, more reliable would be its readings. If the resistance of the voltmeter is comparatively low, it will draw more current from the circuit. Due to this the potential difference across the resistance for the measurement of which the voltmeter was connected, would drop. Therefore a good voltmeter should have such a high resistance so that no or very little current passes through it.

When a voltmeter is connected in a circuit, care should be taken to connect its terminal marked positive (+) to that end of the resistance which is at a higher potential.

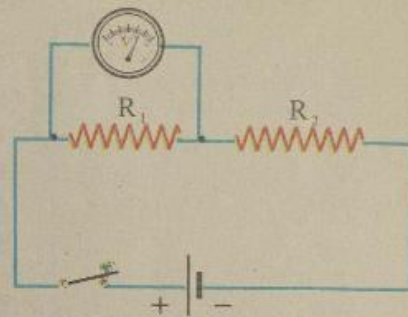


Fig. 16.18

16.6 ELECTRIC ENERGY AND JOULE'S LAW

You have studied that when a positive charge moves from a point of higher potential to a point of lower potential, it gains energy from the electric field. During flow of electric current, positive charges continuously move from a high potential point to a low potential point. Thus the electric current becomes a continuous source of energy.

Consider two points having a potential difference of V volts if one coulomb of charge passes between these points; the amount of energy supplied by the charge would be V Joule. Hence when Q coulomb of charge flows between these two points, then we will get QV joule energy.

If we represent this energy by W , then

$$W = QV$$

As current is the rate of flow of charge, so if a current I ampere flows for time t between two points, then during this time interval $I \times t$ coulomb of charge will flow. So the energy gained during t second

$$W = QV = I \times t \times V \quad \dots\dots\dots (16.13)$$

If a current is passing through a resistance R and the potential difference across its end is V , then by Ohm's law

$$V = I \times R$$

Substituting the value of V in Eq. 16.13

$$W = I^2 R t \quad \dots\dots\dots (16.14)$$

This energy can be utilized for different functions. For example fans convert this energy into mechanical energy, bulb into light and heaters into heat. Usually this energy appears as heat in the resistance. This is the reason that we get heat when current passes through a heater. Eq. 16.14 can be described in words as "the amount of heat energy generated in a resistance due to flow of electric current is equal to the product of the square of current I , the resistance R and the time duration ' t '. This is known as Joule's law.

Electric Power

The amount of energy supplied by current in unit time is known as electric power. Hence power P can be determined by dividing the electric energy W by the time t i.e.,

$$P = \frac{W}{t}$$

By Eq. 16.13

$$P = \frac{QV}{t} = IV = I^2R$$

When current I is flowing through a resistance R , the electric power that generates heat in the resistance is given by I^2R .

The unit of electric power is watt which is equal to one joule per second. It is represented by word W. Electric bulbs commonly used in houses consume 25W, 40W, 60W, 75W and 100W of electric power.

Example 16.6: The resistance of an electric bulb is 500Ω . When a potential of 250V is applied across its end, then find the power consumed by it.

Solution:

$$R = 500 \Omega, \quad V = 250 \text{ V}$$

$$I = \frac{V}{R} = \frac{250 \text{ V}}{500 \Omega} = 0.5 \text{ A}$$

$$P = I^2R$$

$$= (0.5 \text{ A})^2 \times 500 \Omega = 125 \text{ W}$$

Kilowatt hour

Electric energy is commonly consumed in very large quantity for the measurement of which joule is a very small unit. Hence a larger unit of energy is required which is called kilowatt-hour. It is the amount of energy obtained by a power of one kilowatt in one hour.

$$1 \text{ kWh} = 1000 \text{ W} \times 1 \text{ hour}$$

$$= 1000 \text{ W} \times (3600 \text{ s})$$

$$= 36 \times 10^5 \text{ J} = 3.6 \text{ MJ}$$

The energy in kilowatt-hour can be obtained by the following formula.

$$\text{The amount of energy in kilowatt-hour} = \frac{\text{watt} \times \text{time (in hour)}}{1000}$$

The electric meter installed in our houses measures the consumption of electric energy in units of kilowatt-hour according to which we pay our electricity bills. If the cost of one kilowatt-hour i.e., one unit is known, we can calculate the amount of electricity bill by the following formula.

$$\begin{aligned} \text{Cost of electricity} &= \text{number of units consumed} \times \text{cost of one unit} \\ &= \frac{\text{watt} \times \text{time of use in hours}}{1000} \times \text{cost of one unit} \end{aligned}$$

Example 16.7: In a certain house, 4 electric bulbs of 100W each, are daily used for 5 hours. If the rate of electricity is Rs.4 per unit, find the number units consumed in 30 days and what would be its cost?

Solution:

$$\begin{aligned} \text{The number of units consumed} &= \frac{\text{watt} \times \text{time of use (in hours)}}{1000} \\ &= \frac{4 \times 30 \text{ days} \times 5 \text{ h} \times 100 \text{ W}}{1000} \\ &= 60 \text{ kWh} = 60 \text{ units} \end{aligned}$$

$$\begin{aligned} \text{Total Cost} &= \text{number of units consumed} \times \text{cost of one unit} \\ &= 60 \times 4 = \text{Rs. } 240/- \end{aligned}$$

16.7 DIRECT CURRENT AND ALTERNATING CURRENT

You have studied that if positive and negative terminals of a battery are connected to the ends of a conductor, a current begins to flow through it and the direction of its flow is from the positive end of the conductor towards its negative end. Such a current which always flows only in one direction is called direct current or d.c. On contrary to it, there is a current also whose direction changes again and again. This current is called alternating current or a.c. We will explain alternating current from Fig. 16.19. Suppose a resistance R has been connected with a source of voltage which is such that the voltage of its end A changes with respect to the end B in accordance with the graph shown in Fig. 16.20. Here you can see the shape of graph between the time intervals $0 - T$, $T - 2T$ and $2T - 3T$ is exactly the same. The shape of the graph remains same

Do you know?

The power of various appliances in watts.

Fluorescent tube	40
Electric fan	80
Computer	90
Bulb	100
Colour T.V.	120
Refrigerator	500
Electric Iron	750
Toaster	1000
Microwave Oven	1450
Electric Oven	2500
Air-Conditioner	2500

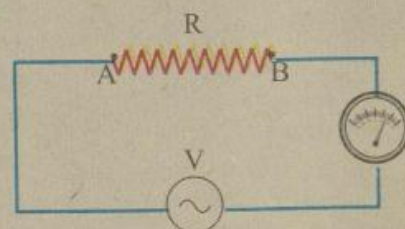


Fig. 16.19

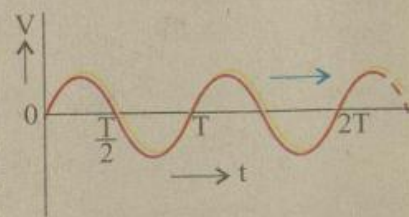


Fig. 16.20: The graph shows the variation of voltage with time.

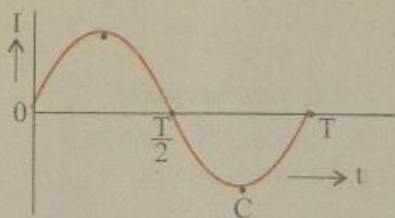


Fig. 16.21: The graph showing variation of current with time t .



Fig. 16.22



Fig. 16.23

Take care



The overloading of the electric socket can cause severe damage.

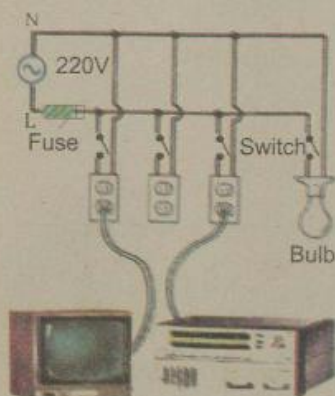


Fig. 16.24

after the time interval T . This time interval after which the voltage repeats its value is known as time period. Now let us examine the type of current which passes through the resistance R due to such a voltage. During the time interval 0 to $T/2$, the potential of the end A is positive with respect to end B , so the current in this interval flows from A to B . It starts from zero, gradually increases to its maximum value and then finally decreases to zero. Hence forth during the interval $T/2$ to T , the potential of end A gets negative with respect to B , so now the current flows in opposite direction from B to A . In this interval also, the current starts from zero, gradually increases to the maximum value in the opposite direction and finally decreases to zero (Fig. 16.21). In this figure positive values of current indicate current flowing from A to B and the negative values from B to A .

After the period $0 - T$, the next period starts. Again in this period from time T to $3T/2$, the current flows from A to B and from $3T/2$ to T from B to A . This continues in subsequent periods. Such a current is known as alternating current or a.c. The set of all the values of current during one period is known as one cycle. The number of cycles which the current completes in one second is known as its frequency. The frequency of a.c. used in our houses is 50 cycles per second.

16.8 ELECTRICITY HAZARDS

Electric energy is distributed to various houses in a city from a power station by means of two wires. One wire is earthed at the power station so it is at zero potential. It is called neutral wire. The other wire is at a certain potential. It is called live wire. Our body is a good conductor of electricity through which current can easily pass. Therefore if a person holds live wire, then because of the presence of voltage in it, current will start flowing to ground through the human body which may prove fatal for the person. In order to avoid such a situation, the wire carrying electricity in the houses should never be naked. Rather it should be covered with an insulator. Such an insulation covered wire is called cable. It is very essential that the layer of insulation in the cable is perfect and is not damaged. But sometimes a heavy current flows through the wire and it gets so hot that its insulation is burnt out and the wire becomes naked and it become dangerous (Fig. 16.22). Similarly constant friction also removes the insulation from the wire whereas too much moisture also damages the insulation. In such a situation it is advisable to use a cable with two layers of insulation (Fig. 16.23).

Safe Use of Electricity in Homes

Fig. 16.24 shows a typical circuit used in houses for the supply of electricity. The various household appliances such as electric bulb, fan, electric iron and T.V. etc., are connected in parallel

with the live and neutral wires through a switch. When any appliance is switched on, the current flows from the live wire to neutral through the appliance and its switch. A specified amount of current can pass through the switch. If the current exceeds this rated value, the switch is damaged after getting heated. Before connecting a switch in the circuit, it should be ascertained that the maximum current that would pass through the switch lies within its rated value. It is very dangerous to connect an appliance directly with the live and neutral wire. The connection is always made through a socket and a plug as shown in Fig. 16.25. When any appliance is desired to connect to a circuit, then its plug is inserted into a socket. Thus terminals of the appliance are connected with live and neutral wires. When switch is turned on, an electric current flows through the appliance.

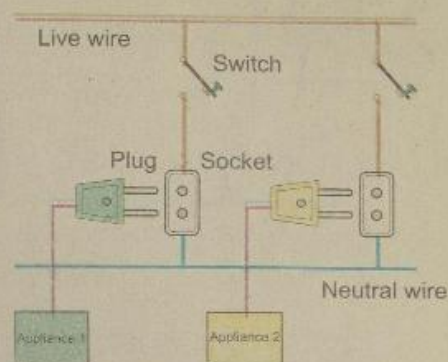


Fig. 16.25

Fuse

Fig. 16.24 shows a small wire connected in series with the live wire. It is known as fuse wire or fuse. A specified value of current can safely pass through it. When the current passing through it exceeds this limit, it gets so hot that it melts. The fuse wire is connected in series, in live wire. If we simultaneously switched on many appliances or due to fault in electrical wiring, live and neutral wires get short, a very heavy current passes which may damage the meter or burn the whole house. Here the fuse wire plays its role. As the fuse wire is in series with the live wire, so the short circuit current also passes through it. This current being much higher than the rated value of the fuse, blows the fuse off. Thus the circuit gets open and the flow of current stops. After removing the fault of the circuit, the blown out fuse is replaced with a new one.

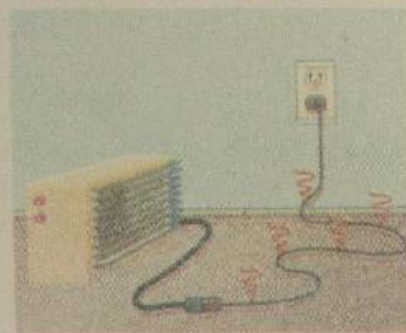
Using Eq. 16.15 we can determine the required fuse rating for a circuit. Suppose we want to insert a fuse for an air-conditioner or heater of power 3000W. If voltage supply is of 240V, then according to relation $P = V \times I$, we get $I = 12.5A$. The available fuses in the market are usually of rating 5A, 10A, 13A, 30A etc. Hence, suitable fuse for this circuit would be of 13A.

Circuit Breaker

It is a safety device which is used in place of fuse (Fig. 16.26-a) Due to any fault when the current exceeds the safety limit, then the button of the circuit breaker moves upward. Due to which the circuit breaks and the flow of the current stops in it. The button of the circuit breaker is pressed after the correction of the circuit. The circuit again gets completed and the current flows in it.

The principle of circuit breaker is explained in Fig. 16.26 (b). When the current flows in the electric circuit, then it flows through the coil

Take care



If you have to use extension wires for some appliance like heater, its resistance should be small so that its insulation does not melt due to overheating.

Do you know ?



By passing more current than the specified value, the fuse wire melts and breaks the circuit.



Circuit Breaker
Fig. 16.26(a)

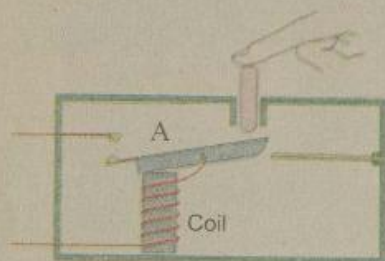
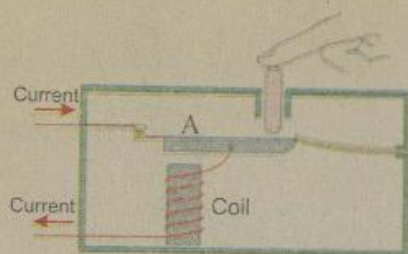


Fig. 16.26(b)

of the circuit breaker also due to which the coil becomes electromagnet. When the current is within its limits, the contact points of the circuit are connected to each other and the circuit is completed. As soon as the current exceeds the limit, the magnetic force of the electromagnet is so increased that it attracts the iron strip 'A' towards it. Hence the contact points are separated and the circuit breaks.

Earth Wire

Most of our appliances such as electric iron, kettle, refrigerators and motors etc. are such that their outer part is of some metal. Usually the outer part is insulated from the live part of the appliance through which the current flows. Because of this insulation no current flows through the outer metal casing and one can safely touch it as we usually do. But sometime due to long use or due to carelessness the insulation is damaged and the outer casing also gets live. Now if some one touches it, he may receive a severe electric shock which may prove even fatal. In order to avoid such a situation, an additional wire is used along with the live and neutral wires. This wire is known as earth wire

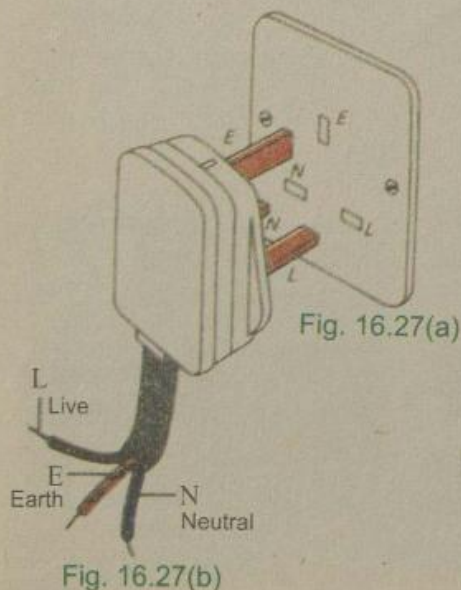
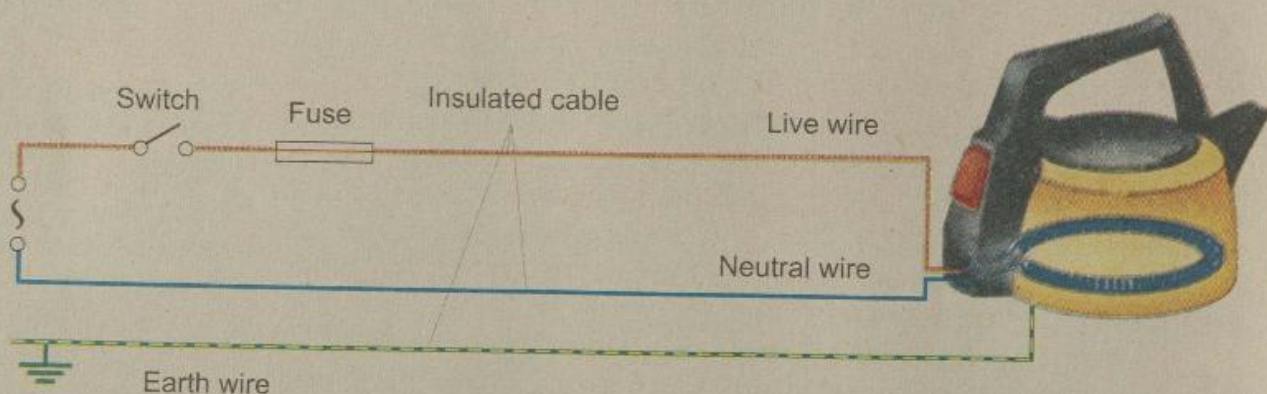


Fig. 16.27(a)

Fig. 16.27(b)

because its one end is connected directly to earth by means of a water pipe leading to ground or by means of an earth terminal. Thus now the electric circuit consists of three wires live, neutral and earth wire (Fig. 16.27-a). This circuit requires three pin sockets and three pin plugs for connection (Fig. 16.27).

Now whenever the metal casing of the appliance, due to faulty insulation, gets connected with the live wire, the circuit shorts and a large current would immediately flow to ground through the earth wire and cause the fuse wire to melt or the circuit breaker breaks the circuit. Therefore, the person which is using the appliance is being saved.

SUMMARY

1. The rate of flow of electric charge through any cross-section is called electric current.
2. It is the SI unit of current. If the current through any cross-section is one ampere, then one coulomb of charge would pass through that surface in one second.
3. It is the total amount of energy supplied by the battery or the cell in driving one coulomb of charge once round a complete circuit in which the cell is connected.
4. The current I passing through a conductor is directly proportional to the potential difference V applied across its ends provided the temperature and physical state of the conductor do not change.
5. Resistance is a measure of opposition to the flow of current through a conductor. Ohm is its unit.
6. Galvanometer is a sensitive instrument which detects current in a circuit.
7. Ammeter is an instrument which measures current.
8. Voltmeter is an instrument used to measure potential difference between two points.
9. The amount of heat energy generated in a resistance due to flow of electric current is equal to the product of the square of current, resistance and the time interval ($W = I^2Rt$). This is called Joule's law.
10. Kilowatt hour is the amount of energy obtained from a power of one kilowatt in one hour. It is equal to 3.6 mega joule.
11. The current which does not change its direction of flow is known as direct current or d.c.
12. It is a current which changes its direction of flow again and again, is known as alternating current or a.c.

QUESTIONS

- 16.1 Define electric current. In what unit is it measured? Explain the mechanism of the flow of current through a conductor.
- 16.2 What is meant by conventional current? Explain.
- 16.3 What is electromotive force? Differentiate between electromotive force and potential difference.
- 16.4 State Ohm's law. What are its limitations?
- 16.5 What is meant by resistance of a conductor. Define an ohm.
- 16.6 What are the factors upon which the resistance of a conductor depends? What is meant by specific resistance?
- 16.7 Why does the resistance of a conductor increase with the rise of its temperature? Describe a resistance thermometer.
- 16.8 How are resistances connected in series? Describe the characteristic features of this combination. What is meant by equivalent resistance of a series combination? Find its value.
- 16.9 How are resistances connected in parallel? Describe the characteristic features of this combination. What is meant by equivalent resistance of a parallel combination? Find its value.
- 16.10 Briefly explain ammeter and voltmeter.
- 16.11 Describe Joule's law.
- 16.12 What is kilowatt-hour? How can the cost of electricity consumed in a house be calculated?
- 16.13 Compare d.c. and a.c.
- 16.14 What types of risk are involved in the use of electricity in houses? What safety measures should be adopted to avoid these risks.
- 16.15 Three possible answers have been given for each of the following questions. Mark (✓) on the correct answer.
 - (i) The unit of current is known as
 - (a) volt
 - (b) ohm
 - (c) ampere

- (ii) As the temperature of a conductor rises, its resistance
(a) increases (b) decreases
(c) does not change
- (iii) When resistances are connected in series, the current passing through them is
(a) different (b) zero
(c) the same
- (iv) The equivalent resistance of a parallel combination is
(a) equal to sum of all the resistances.
(b) is greater than the largest resistance of the combination.
(c) is smaller than the smallest resistance of the combination.

NUMERICAL PROBLEMS

- 16.1 500 mA current is passing through a wire. Find the amount of charge that will flow through it in one hour.
(1800 C)
- 16.2 Potential difference of 10V is applied across a conductor. If a current of 1.5 A is passing through it, how much energy would be obtained from the current in 1 min.
(900 J)
- 16.3 When a potential of 10V is applied across a conductor, a current of 5mA flows through it. Find the resistance of the conductor.
(2k Ω)
- 16.4 The resistance of a conductor is 10M Ω . If a potential of 100 volt is applied across its end, then find the current passing through it in mA.
(0.01 mA)
- 16.5 What would be the length of a copper wire of 3 mm diameter so that its resistance is equal to 0.005 ohm. Specific resistance of copper is $1.69 \times 10^{-8} \Omega\text{m}$.
(2.1 m)
- 16.6 Two resistances of 2k Ω and 8k Ω are connected in series. If a 10V battery is connected across the ends of this combination, find the following quantities.
(a) The equivalent resistance of the series combination.
(b) Current passing through each of the resistances.
(c) The potential difference across each resistance.
[(a) 10k Ω (b) 1mA (c) 2V, 8V]
- 16.7 Two resistances of 6k Ω and 12 k Ω are connected in parallel. A 6V battery is connected across its ends. Find the values of the following quantities.
(a) Equivalent resistance of the parallel combination.
(b) Current passing through each of the resistances.
(c) Potential difference across each of the resistance.
[(a) 4k Ω (b), 1mA, 0.5 mA, (c) 6V]
- 16.8 An electric motor is running with 220V and 1.5 A current. Find the energy supplied by it in kilowatt-hour in 5 hours.
(1.65 kWh)
- 16.9 An electric bulb is marked with 220V, 100W. Find the resistance of the filament of the bulb. If the bulb is used 5 hours daily, find the energy in kilowatt-hour consumed by the bulb in one month (30 days).
(484 Ω , 15 kWh)
- 16.10 A house is installed with
(i) 10 bulbs of 60 W each which are used 5 hours daily.
(ii) 4 fans of 75 W each of which runs 10 hours daily.
(iii) One electric iron of 1000 W which is used 2 hours daily.
(iv) One T.V. of 100 W which is used 5 hours daily.
(v) If the cost of one unit of electricity is Rs.4. Find the monthly expenditure of electricity (1 month = 30 days).
(Rs.1020/-)

17

ELECTROMAGNETISM

In this chapter you will learn:

1. The magnetic effects of electric currents .
2. Force acting on a current carrying conductor in a magnetic field.
3. Turning effect of magnetic field on a current carrying coil.
4. Direct current motor.
5. Electromagnetic induction.
6. A.C generator.
7. Self and mutual induction.
8. Transformer.

17.1 MAGNETIC EFFECTS OF ELECTRIC CURRENT

When current passes through a conductor, a magnetic field is produced in the space around it. If the conductor is a straight wire, the lines of force of this magnetic field would be in the form of concentric circles (Fig. 17.1). These lines of force can be traced on a piece of cardboard with the help of a compass needle.

The direction of the lines of force can be determined by the right hand rule according to which if we grasp the current carrying conductor in our right hand with the thumb being stretched in the direction of current, the fingers would curl in the direction of lines of force (Fig.17.2).

This rule shows that if the current is flowing through wire from bottom end to top then the direction of lines of force would be anticlockwise (Fig. 17.3-a). On the contrary if the current is flowing from top towards the bottom, it would be clockwise (Fig.17.3-b).



Fig. 17.1



Fig. 17.2

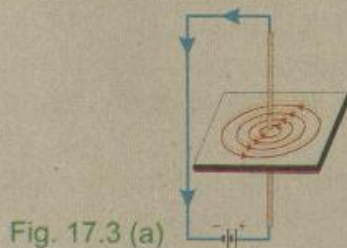


Fig. 17.3 (a)

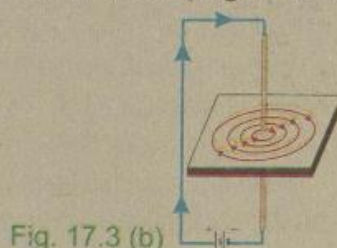


Fig. 17.3 (b)

A coil of few turns of wire is shown in Fig. 17.4. Its two ends are connected with a battery so that a current is passing through it. In Fig. 17.4(b) vertical cross section of a single turn of this coil has been shown by a small circle. The direction of current has been indicated by placing a dot or a sign of multiplication in these circles. A dot indicates that the current is directed out of the plane of the paper, i.e., it is flowing towards us where as a sign of cross ($\times$) would mean that the current is directed into the paper i.e; it is flowing away from us.

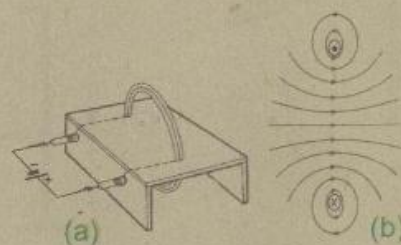


Fig. 17.4

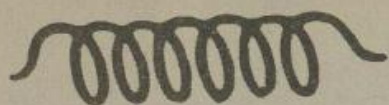


Fig. 17.5 (a)

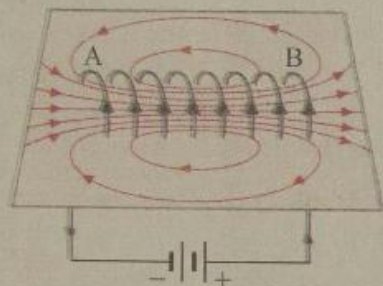


Fig. 17.5 (b)

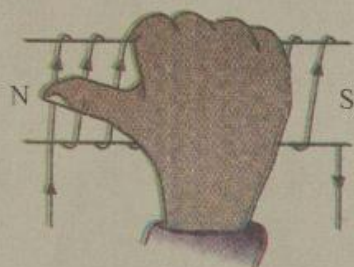


Fig. 17.6

(Fig. 17.4b) shows the magnetic lines of force generated by the flow of current in this coil. These lines are straight and parallel in a small region near the centre of the coil and are directed perpendicular to its plane. They are approximately circular near the wire. Thus the field is uniform in a small area surrounding the centre of the coil. In the remaining portion it is non-uniform. The direction of the field, i.e; that of the lines of force can be determined by the right hand rule.

Magnetic field of a current carrying solenoid.

A solenoid is a closely wound cylindrical coil of insulated wire (Fig.17.5a). Fig. 17.5(b) shows the magnetic lines of force generated by the passage of current through a solenoid. These lines emerge out from one end of the solenoid and after encircling around, enter into it through the other end. Inside the solenoid, the lines of force are parallel and all point in the same direction. It can be seen that these lines resemble the pattern of the lines of force due to a bar magnet. On the basis of this resemblance we can say that one end of the solenoid behaves like a north pole and the other, like a south pole. As the lines of force emerge out of the north pole of a magnet and enter into it through the south pole, therefore in Fig. 17.5(b), the end B of the solenoid would be north pole and end A would be a south pole. The polarity of a current carrying solenoid can be determined by the following rule.

Hold the solenoid in your right hand by curling the fingers in the direction of the current; the stretched thumb would indicate towards the north pole (Fig. 17.6).

The poles of a solenoid can also be found out by the following easy rule.

Hold down the end of the current carrying solenoid in front of you, if the direction of current flow through this end is anticlockwise, it would be north pole, otherwise it would be a south pole.

17.2 FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

When a current carrying conductor is placed in a magnetic field at right angles to it, it experiences a force as demonstrated by the following experiment.

Fix two iron nails into the opposite faces of a large size cork. The nails should be in line with each other and should not touch inside the cork. Clamp the cork on a stand so that the nails are horizontal. Now take a thick wire and bend it in the shape of U. Make hooks at its two ends. With the help of these hooks, suspend the U shape wire from the two nails so that the horizontal part of the wire passes through the space between the pole pieces of a horse shoe magnet (Fig. 17.7). Connect the two nails with a battery and a switch. As the key is pressed, current starts flowing through the U shaped wire and simultaneously the wire moves inwards. This movement of the wire is due to the force which is acting on the side AB of the wire. If the direction of current shown in Fig. 17.7 is

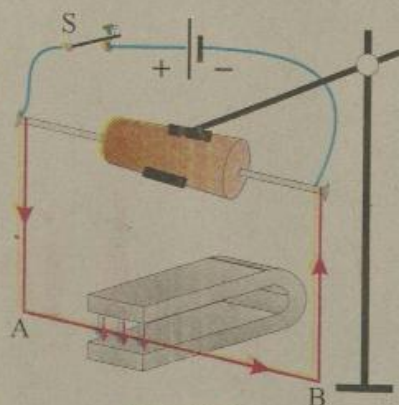


Fig. 17.7

reversed, the wire moves outwards. The direction of the force acting on the side AB of the wire can be determined by Fleming's left hand rule.

According to this rule, stretch the thumb, forefinger and the middle finger of the left hand mutually at right angles to each other. If the forefinger points in the direction of the magnetic field, the middle finger in the direction of the current, then the thumb would indicate the direction of the force acting on the conductor (Fig. 17.8).

It can be seen that the direction of the force acting on the conductor in Fig. 17.7 is in accordance with Fleming's left hand rule. Note that the force acting on the current carrying conductor is at right angles to both the directions of current and magnetic field.

If instead of 90° the current carrying conductor makes an angle θ with the magnetic field (Fig. 17.9), experiment has shown that the force acting upon the conductor in such a case is directly proportional to $\sin \theta$. As such the force acting upon the conductor is maximum only when it is placed at right angles to the field. If the conductor is placed parallel to the field, no force would act upon the conductor because the value of $\sin \theta$ is zero in this case.

17.3 TURNING EFFECT ON A CURRENT CARRYING COIL IN A MAGNETIC FIELD

A rectangular coil ABCD has been placed in between the pole pieces of a magnet in such a way that it can freely rotate about its axis in the space between the poles. The initial position of the coil is shown in Fig. 17.10. In this position, the sides AB and CD of the coil are perpendicular to the field, whereas the side BC and DA are parallel. Now if the ends of the coil are connected to the positive and negative terminals of a battery, a current would start flowing through the coil as shown in Fig. 17.10. The direction of the current in the sides BC and DA is parallel to the magnetic field, so no force would act on these sides. In sides AB and CD, the direction of current is at right angles to the field, so force would act on these sides. According to Fleming's left hand rule, the forces acting on these perpendicular sides would act horizontally in the opposite directions (Fig. 17.10). The magnitude of these forces would be equal. Under the action of these two equal but opposite forces, a couple would act on the coil due to which it would start rotating.

17.4 D.C. MOTOR

D. C. Motor consists of a rectangular coil abcd mounted on a spindle so that it can rotate between the poles of a permanent magnet. A copper ring is fixed on the spindle of the coil. This ring is split into two halves, S_1 and S_2 . One end of the coil is soldered with the split ring S_1 and the other to split ring S_2 . Two carbon brushes X, Y are caused to press lightly against the rings by means of springs (Fig. 17.11). When these brushes are connected to a battery, the coil starts rotating. Suppose when the current is switched

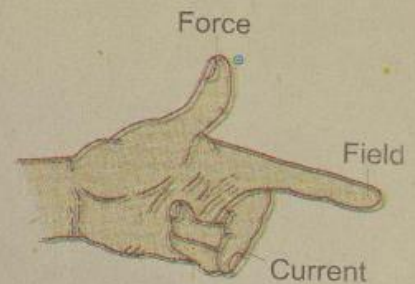


Fig. 17.8

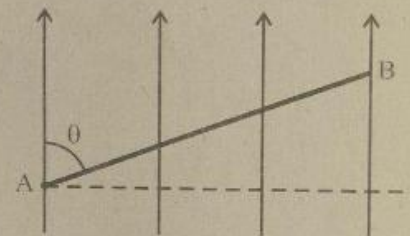


Fig. 17.9

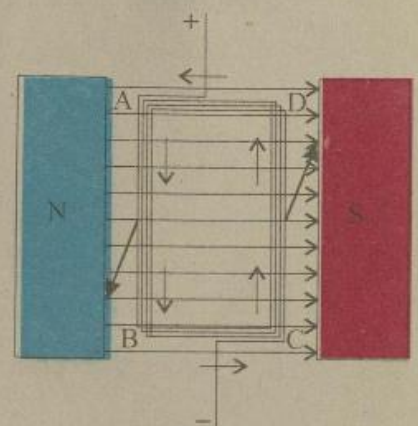


Fig. 17.10

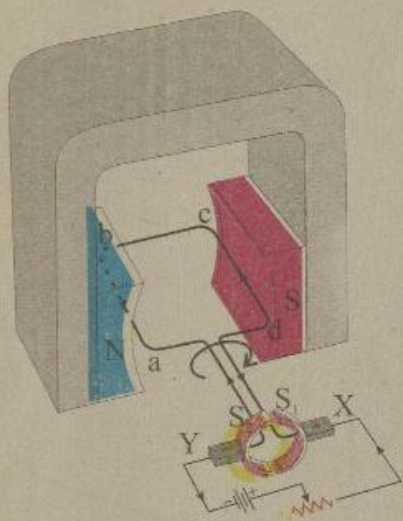


Fig. 17.11

on, the coil is in horizontal position. In this position, the split ring S_1 is in contact with brush X and split ring S_2 is in contact with brush Y. The current flows through the different sides of the coil in the direction as shown in Fig. 17.11. According to Fleming's left hand rule, the force acting on side ab is directed upward and that on side cd is directed downwards. Under the action of these two equal but opposite forces, a couple acts upon the coil, which causes it to rotate in the clockwise direction. When the coil reaches the vertical position, the brushes reach to the vacant space between the split rings and their connection with the coil is cut off. In spite of the fact that there is no current flow, the coil instead of becoming stationary, it continues to move beyond this vertical position because of its momentum and the connection of split ring with the brushes is again established. But this time brush X is in contact with the split ring S_2 and brush Y is in contact with the split ring S_1 . In this way, the direction of current flow in the coil is reversed. Now the side ab is on the right hand side with a downward force acting on it and side cd is on left hand side with an upward force acting on it. Thus the coil continues to rotate in clockwise direction for so long as the battery is supplying the current to the coil. In this way the D.C. motor converts the electrical energy into mechanical energy, which is utilized for different types of work.

17.5 ELECTROMAGNETIC INDUCTION

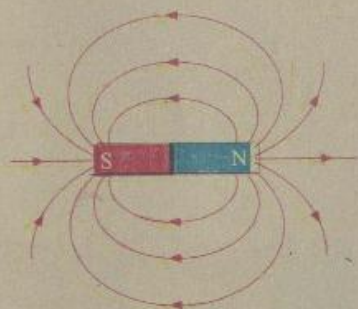


Fig. 17.12

Magnetic lines of force can be drawn in any magnetic field. We have seen that in the magnetic field of a current carrying wire, the lines of force are in the form of concentric circles (Fig. 17.1). In the case of a bar magnet the lines start from the north pole and after passing around the magnet, end at the south pole. Then they pass from south pole to the north pole through the magnet, thus making a closed loop (Fig. 17.12).

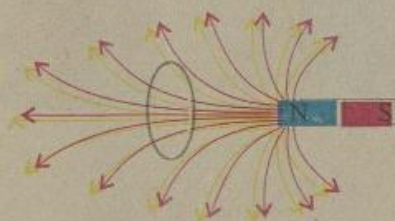


Fig. 17.13 (a)

If a coil is placed in the magnetic field of a bar magnet, some of the lines of force will pass through its face. If the coil is far away from the magnet, only a few lines of force will also pass through it. On the other hand, if the coil is close to the magnet, a large number of lines of force will pass through it (Fig. 17.13). The number of magnetic lines of force passing through any surface is known as magnetic flux through that surface.

If the magnetic flux through a coil or a solenoid is changing, an emf is induced in it. Let us demonstrate this through an experiment.

Take a solenoid and connect a galvanometer with its two ends (Fig. 17.14).

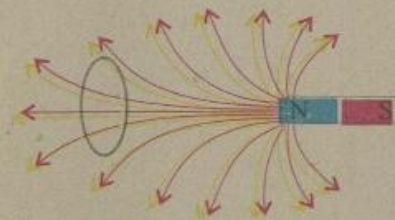


Fig. 17.13 (b)

- i. If the north pole of a bar magnet is quickly moved towards the end A of the solenoid, the needle of galvanometer gets deflected which shows that an emf has been generated in the solenoid due to which a current flows through the galvanometer. This current is known as induced current (Fig. 17.14-a).

Now stop the motion of the magnet, you will see that as soon as the magnet stops moving, the deflection in the galvanometer gets zero. This means that induced current flows only when the magnet is moving.

The amount of deflection in the galvanometer depends upon the speed of the magnet. Higher the speed, the larger is the value of induced current in the circuit.

ii. If the north pole of the magnet is moved away from the end A, again the galvanometer shows a deflection but this time, in opposite direction (Fig. 17.14-b).

iii. When the south pole of the magnet is brought close to end A of the solenoid or moved away from it, an induced current flows through the galvanometer but the direction of this current is opposite to that of the current induced in case of north pole.

iv. Similar results will be obtained if the magnet is kept stationary and the solenoid is moved towards or away from the magnet.

From this experiment we conclude that an emf is induced in the coil when there is a relative motion between the coil and the magnet. The magnitude of this induced emf depends upon the speed of relative motion. This phenomenon is known as electromagnetic induction. Micheal Faraday discovered it in 1831. According to Faraday when a magnet is moved towards or away from a coil, the magnetic flux associated with the coil changes due to which an emf is induced in the coil.

The value of the induced emf is directly proportional to the rate of change of flux. This is known as Faraday's Law of Electromagnetic Induction.

17.6 A.C. GENERATOR

If a coil is rotated in a magnetic field, the magnetic flux passing through it would be maximum when its position is perpendicular to the lines of force (Fig. 17.15-a) and the flux would be zero (Fig 17.15-b) when its plane is parallel to the lines of force because in this position, the lines do not cut through the surface of the coil. Thus, when a coil rotates in a magnetic field, the flux passing through it continuously changes. This change of flux induces an emf in the coil. This is the principle on which an A.C generator works.

A simple generator consists of a rectangular coil, which is rotated between the poles of a permanent magnet. Both the ends of the coil are soldered to the two slip rings fixed on the arm of the coil (Fig. 17.16).

Two carbon brushes are kept in contact with these slip rings with the help of two springs. Current is drawn from the coil through these brushes. When the coil is rotated between poles of the magnet, a current is induced in accordance with the principle

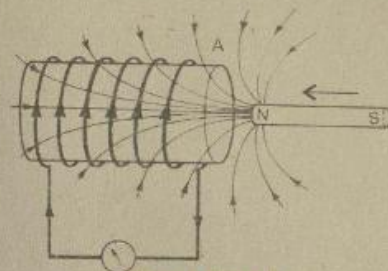


Fig. 17.14 (a)

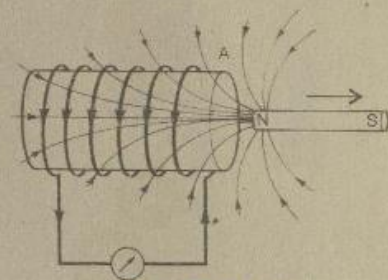


Fig. 17.14 (b)

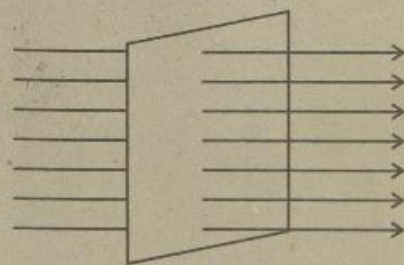


Fig. 17.15 (a)

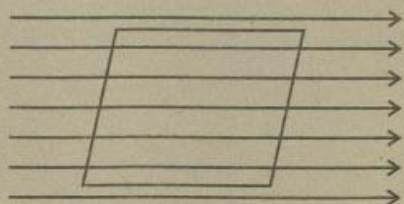


Fig. 17.15 (b)

described above. This current after passing through the slip rings and the carbon brushes flows into the circuit.

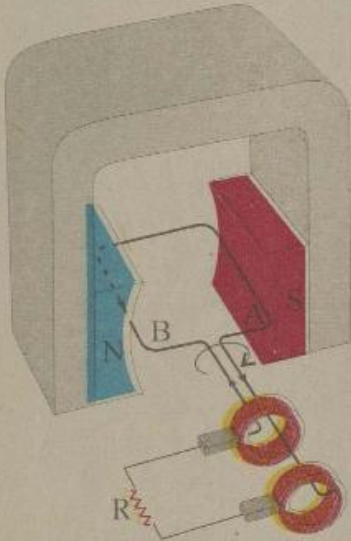


Fig. 17.16

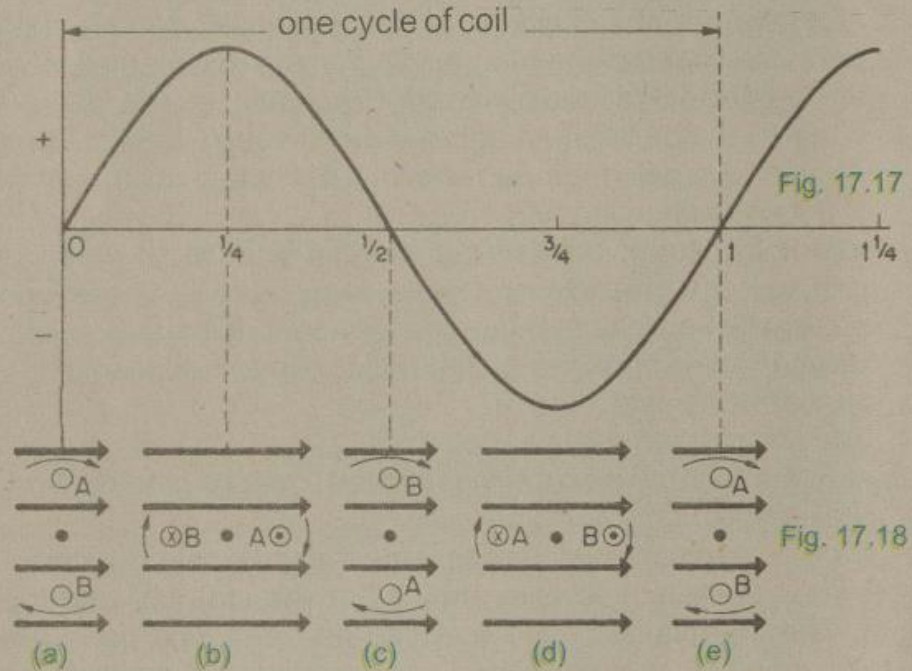


Fig. 17.17

Fig. 17.18

Fig 17.17 shows the emf that is generated during one complete rotation of the coil. Suppose in the beginning the coil is vertical with its side A upward and side B downward as shown in Fig. 17.17(a). In this figure the sides A and B have been shown by their vertical sections. In this position the sides A and B are moving parallel to the field due to which the rate of change of flux through the coil is zero. So, according to Faraday's law, the emf induced in the coil is zero (Fig.17.18 point O). After completing one quarter of the rotation, the position of the coil is shown in Fig.17.18(b). At this instant both the sides A and B are moving at right angles to the field and the rate of change of flux through the coil is maximum. Hence the emf induced at this instant is maximum (Fig.17.17 point $1/4$). After one half rotation of the coil, the position of sides A and B is shown in Fig 17.18 (c). Now again the sides are moving parallel to the field, so the emf induced is zero (Fig 17.17, point $1/2$). In this position, the side A is located downward and side B upward. As the coil further rotates, the direction of induced emf changes. After completing three quarters of its rotation, the coil assumes the position as shown in Fig. 17.18(d). At this instant, the emf is at its maximum value but its direction is opposite to that of Fig. 17.17 (point $1/4$).

The position of the coil after one complete rotation is shown in Fig. 17.18(e). Now the emf is again zero because this position is the same as shown in Fig.17.18(a). Henceforth the coil starts its next rotation and with it, the next cycle of induced emf also starts. In this way the rotation of the coil in a magnetic field generates an alternating induced emf.

For Your Information



This robot after sensing the magnetic field of the underground current cable can indicate the passage of cable.

17.7 MUTUAL INDUCTION

Fig. 17.19 shows two coils X and Y, placed close to each other. The coil X has been connected with a battery and a switch, whereas a sensitive galvanometer is connected with the coil Y. We observe that as soon as the switch of the coil X is closed, the galvanometer connected with the coil Y shows a momentary deflection indicating a momentary flow of current through the coil Y in spite of the fact that the two coils are quite separate having no electrical connection between them.

Similarly at the instant when the flow of current in the coil X is stopped by putting its switch off, the galvanometer connected with the coil Y again shows a deflection but this time its direction is opposite to that of the previous case.

We can explain these observations on the basis of magnetic flux passing through the two coils.

As soon as the switch connected with coil X is closed, a current begins to flow in it and with it, its magnetic field begins to build up (Fig. 17.19). Some of the lines of force of this field start passing the neighbouring coil Y, which results in the change of magnetic flux to take place through the coil Y due to which a current is induced in its circuit. As soon as magnetic field of coil X attains its constant value, it stops increasing due to which the increase in flux through the coil Y also stops. Hence the induced current reduces to zero. The magnetic field of coil X attains its constant value within a few moments, after the closure of its switch, therefore the current induced in coil Y is also momentary.

Similarly when the switch of the coil X is opened, the flow of current through it stops and in few moments its magnetic field reaches to zero. The flux through the coil Y decreases to zero due to which current is again induced in it. As this current is induced due to the decrease in flux, so its direction is opposite to the direction of the previous momentary current because that current was induced in the coil Y due to increase in the value of magnetic flux.

If a current is induced in a circuit due to a change of current in another circuit, this phenomenon is known as mutual induction.

The coil in which the change in current produces induced current in another coil is known as primary coil and the second coil in which current is induced is known as a secondary coil.

17.8 SELF INDUCTION

The number of lines of force in a magnetic field depends upon the strength of the field. A stronger field has more lines than a weaker one.

We have read that as current passes through a coil, it produces a magnetic field whose lines of force pass through the different turns of the coil (Fig. 17.5b). If the current passing through the coil changes, then the magnetic field produced by it also changes which results in a change in the number of lines of force passing through the coil. In other words, the magnetic flux linked

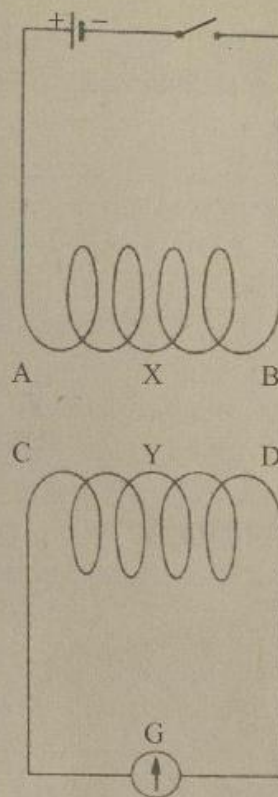


Fig. 17.19

Interesting Information



How some birds, like pigeon, correctly estimate the direction? There is some sort of natural magnet in their head.

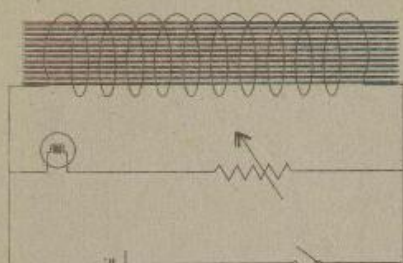


Fig. 17.20

Do You Know ?



Transformer works on the principle of mutual induction. It is an important part of most of the electronic devices.

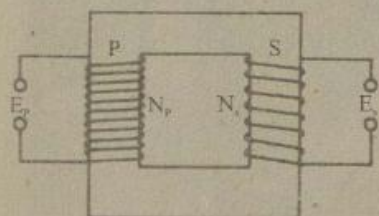


Fig. 17.21 (a)

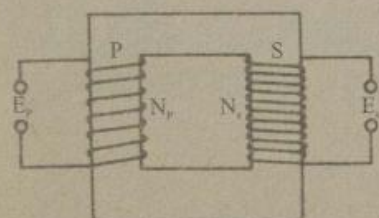


Fig. 17.21 (b)

with the coil changes. This causes an induced emf in the coil which is known as self induced emf and this phenomenon is called self induction.

The phenomenon of self induction can be demonstrated by the experiment shown in Fig. 17.20.

When the switch is put on, the bulb does not light up because the battery voltage is not sufficient for this purpose. However when the switch is put off, the lamp flashes lightly for a few moments, indicating that a voltage higher than that of the battery, has been instantaneously supplied by the coil to the bulb due to which the bulb flashes. This large voltage is the self induced voltage produced in the coil at the instant when the switch is put off.

17.9 TRANSFORMER

This is an electrical device which is used to increase or decrease the value of alternating voltage.

It consists of two coils which are wound on two different sides of a rectangular iron core (Fig. 17.21). One coil is called primary and the second one is known as secondary. The alternating voltage whose value is to be altered, is supplied to the primary due to which an alternating current begins to flow through it. This current creates a continuously changing magnetic flux through the primary coil. The iron core enhances the magnetic flux to a very large value and also concentrates it into the core with the result that practically the whole of flux generated by the primary coil is also linked up with the secondary. As this flux is continuously changing, therefore, in accordance with the principle of mutual induction, an alternating voltage is induced across the secondary coil. The value of this voltage depends upon the number of turns in the primary and secondary coils. If

N_p = number of turns in the primary coil.

N_s = number of turns in the secondary coil.

E_p = voltage applied across the primary which is to be altered.

E_s = the required voltage generated across the secondary coil;

Then we can prove that

$$\frac{E_s}{E_p} = \frac{N_s}{N_p} \quad \dots\dots\dots (17.1)$$

According to this formula, if the voltage applied across the primary coil is to be decreased, i.e., $E_s < E_p$, then N_s would also be smaller as compared to N_p . That is, the number of turns in the secondary would be smaller than the number of turns in the primary. Such a transformer is known as step down transformer (Fig. 17.21a). On the other hand, if the voltage applied to the primary coil is to be increased, the number of turns in the secondary would be larger as compared to number of turns in the primary. Such a transformer is known as a step up transformer.

SUMMARY

1. When electric current passes through a conductor, a magnetic field is set up in the space surrounding the conductor. In case of a straight current carrying conductor, the lines of force are in the form of concentric circles.
2. When a straight current carrying conductor is placed perpendicularly in a magnetic field, it experiences a force in a direction at right angles to both the directions of the field and the current.
3. When a current carrying coil is placed in a magnetic field, it experiences a couple due to which the coil begins to rotate. A D.C. motor operates on this principle. It converts electrical energy into mechanical energy.
4. The number of magnetic lines of force passing through a certain surface is known as the magnetic flux through that surface.
5. When magnetic flux through a coil is changing, an emf is induced in it. The value of this induced emf is directly proportional to the rate of change of flux. This is known as Faraday's Law of Electromagnetic Induction.
6. An A.C. generator consists of a coil. When this coil is made to rotate in a magnetic field, the magnetic flux through it continuously changes due to which an alternating voltage is induced in it.
7. If the change of current in a circuit induces a current in another circuit this phenomenon is known as mutual induction.
8. If the current through a coil or a circuit changes and this change induces an emf in the circuit itself, the phenomenon is known as self induction.
9. Transformer is an electrical device which is used to increase or decrease the value of an alternating voltage.

QUESTIONS

17.1. Draw the magnetic lines of force in the following cases.

- a. straight current carrying conductor.
- b. current carrying coil.
- c. current carrying solenoid.

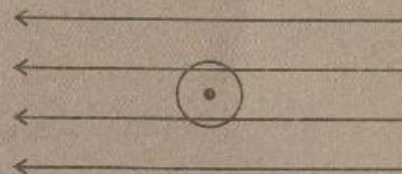
17.2. State the rule by which the direction of the lines of force can be determined in the case of a straight current carrying conductor.

17.3. State the rule by which the polarity of current carrying solenoid can be found out.

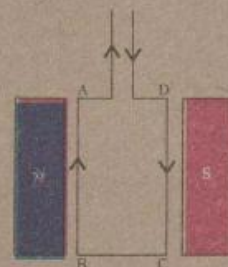
17.4. Describe an experiment to show that when a straight current carrying conductor is placed in a magnetic field, it experiences a force. State the rule by which the direction of this force can be determined.

17.5. The figure shows the cross-section of a straight current carrying wire. The arrows represent the magnetic field in which the wire has been placed. Indicate the force acting on the wire by

an arrow sign.



17.6. The figure shows a current carrying coil suspended in between the pole pieces of a horseshoe magnetic. The arrow indicates the direction of the



current flow through the coil. Explain whether the coil would rotate in the clockwise or anticlockwise direction.

17.7. Describe the construction and method of working of a D.C. motor. Also explain why the split rings are needed in it?

17.8 Show by an experiment that a current can be induced in a coil by a magnet. What are the factors upon which the value of this current would depend?

17.9 State Faraday's law of electromagnetic induction.

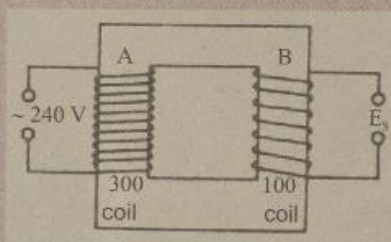
17.10 Describe an A.C. generator and explain the form of voltage generated by it.

17.11 What is meant by self induction? Describe an experiment to show the voltage generated by self induction.

17.12 What is meant by mutual induction? Describe an experiment to demonstrate this phenomenon.

17.13 Describe the construction and working of a transformer.

17.14 A transformer has been shown in figure. Which of its coil is primary and which one is secondary? What would be the value of the output voltage?



What type of transformer is this?

(80 V)

17.15 A step down transformer changes 250 volts A.C. into 6 volt A.C. If the number of turns in its primary is 10000, find the number of turns in its secondary.

(240)

17.16 Four answers have been given to each of the following questions. Mark (✓) on the right one.

a. The shape of magnetic lines of force in case of a straight current carrying conductor is

- i. elliptical
- ii. triangular
- iii. rectangular
- iv. circular

b. When a straight current carrying conductor is placed in a magnetic field at right angles to it, the direction of force acting upon it is

- i. the same as the direction of field..
- ii. opposite to the direction of the field.
- iii. makes an angle of 45° with the current.
- iv. at right angles to both the field and the current.

c. A transformer has 100 turns in its primary and 500 turns in the secondary. If 6 volts D.C is applied across its primary, the voltage induced across its secondary would be

- i. 0 Volts
- ii. 30 Volts
- iii. 45 Volts
- iv. 60 Volts

18

ATOMIC AND NUCLEAR PHYSICS

In this chapter you will learn:

1. Atomic structure.
2. Natural radioactivity.
3. Half life.
4. Radio isotopes.
5. Einstein's mass-energy equation.
6. Nuclear fission and fusion.

18.1 ATOMIC STRUCTURE

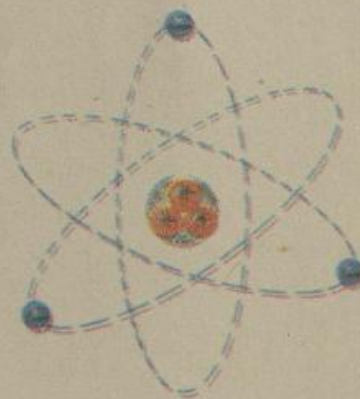
In the previous classes you have studied that the smallest part of an element is called an atom. You also know that the atom consists of two parts and its central part is called a nucleus. The nucleus consists of protons and neutrons. The proton is a positively charged particle. So the nucleus carries a positive charge. The electrons revolve round the nucleus in nearly circular orbits. Since an atom is a neutral particle, so the number of electrons in it is equal to the number of protons. The mass of the proton & neutron is nearly the same i.e., 1.67×10^{-31} kg. Since the protons and neutrons exist inside the nucleus so these are called nucleons.

A nucleon is nearly 1832 times heavier than an electron. So the mass of an atom is nearly equal to the total sum of the masses of all the protons and neutrons present in the nucleus of that atom. The total number of protons and neutrons in the nucleus is called the Atomic Mass Number and is denoted by the letter A. Since the number of protons in an atom of different elements is different so the number of protons in the nucleus indicate the charge on that nucleus. The number of protons in a nucleus is called the charge number or Atomic number and is denoted by the letter Z. Similarly the number of neutrons in the nucleus is denoted by the letter N.

If atomic number of an atom is A and its Atomic Mass Number is Z, then this atom is represented by the symbol ${}_Z^AX$ which is called a nuclide. For example there is only one proton in the nucleus of hydrogen atom so its atomic number is 1 and its atomic mass number is also 1. Hence it is denoted by ${}_1^1H$.

The experiments have shown that in the atoms of some elements, the number of protons is the same, due to which the chemical properties are the same, but the total number of nucleons in their nuclei is different. Such elements are called Isotopes.

Isotopes are those elements whose atomic numbers are the same but their atomic mass numbers are different.



The nucleus of an atom consists of protons and neutrons.

18.2 NATURAL RADIOACTIVITY

In 1896 a French scientist, Henry Becquerel, was conducting some experiments on the compounds of Uranium in connection with X-ray. In those days there was no sunlight due to cloudy weather. So he kept this compound in a paper and placed it in a drawer where there were already placed some photographic plates covered in black paper. After a few days he found that the photographic plates carry some impressions. From it he concluded that the Uranium Salt, even in the absence of sunlight, emits radiations which pass through the wrapping paper and affect the photographic plates. In order to test his conclusion, he performed many experiments.

Becquerel took a closed box into which no light could enter and placed in it the uranium salt and the photographic plates near to each other and also separated by aluminium sheets. In both the cases, he obtained the same results. This showed that strong radiations are emitted by the uranium salt and they are not affected by the absence or presence of the sunlight. It does not matter even which compound of uranium is used. Whether this compound is in the solid or in the liquid state. Afterwards, with the discovery of thorium, polonium and radium etc., and the same actions found in these elements, the phenomena was termed as radioactivity.

Radioactivity is such a process in which the elements with the charge number greater than 82, naturally keep on radiating.

During that process three different types of radiations are emitted which are termed as Alpha (α), Beta (β) and Gamma (γ) radiations.

Since this is the natural property of elements so it is called natural radioactivity and these elements are called radioactive elements. Now-a-days, using modern techniques, the elements, which are much lighter than the natural radioactive elements, are made radioactive. Such elements are known as artificial radioactive elements.

The atoms of radioactive elements change into atoms of the other elements due to the emission of radiations. This breaking process is spontaneous and continues for a long time and is irreversible.

The radioactive elements whose atomic numbers are the same but have different atomic mass numbers are called Radioactive Isotopes.

In order to study the nature of radiations emitted due to radioactivity, Rutherford and others performed an experiment as described below:

Experiment

A small quantity of the Radium source was placed in a hole dug in a block of lead (Fig. 18.1) so that parallel rays may come out

of the nasal at S. A photographic plate was placed at some distance above the block so that all the radiations fall on this plate. All of these were placed in a lead chamber which was evacuated with the help of a pump, so that the radiations may not be absorbed by air. A magnetic field was applied on this chamber vertically downwards, i.e., the magnetic field was perpendicular to the plane of the paper and directed inwards. After some time, when the photographic plate was developed, it carried black spots at three different points which showed that these radiations are of three types (Fig. 18.1). The spot on the left is due to the arc of a large circle indicating a group which carried positively charged particles, called α rays. The spot situated on the arc of a small circle on the left, indicates the presence of negatively charged particles. These are known as β rays. The spot in the middle indicates the particles which do not have any charge and are known as γ rays.

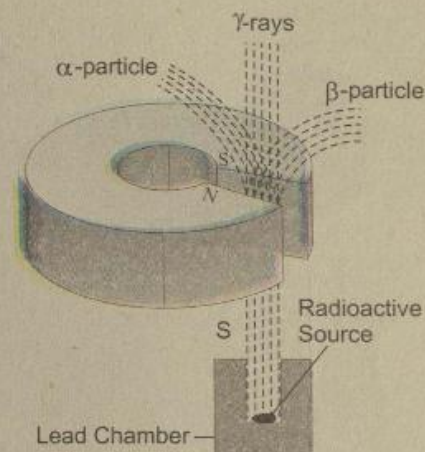


Fig. 18.1

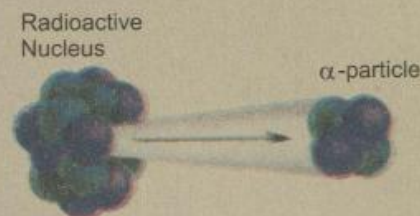
Properties of Alpha (α), Beta (β) and Gamma (γ) rays

Alpha (α) rays

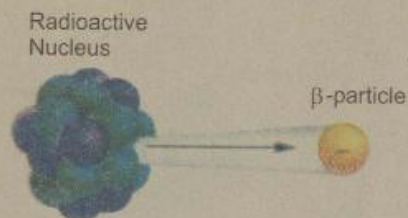
1. The α rays are emitted by radioactive elements. Their speed ranges between 1.4×10^7 and 1.7×10^7 ms⁻¹. The speed of these rays depends upon the radioactive element from which these are emitted. Their speed is different for different elements, but the speed of all the α rays emitted by one element is the same.
2. α rays ionize the gas through which they pass.
3. α rays affect the photographic plates.
4. They produce fluorescence in Zinc sulphide.
5. At atmospheric pressure they travel a small distance in air. This distance is different for α rays emitted by different elements. For example the range for α rays emitted by Uranium is 2.7 cm while is 8.62 cm for α rays emitted by Thorium.
6. The atomic and magnetic fields affect the α rays which shows that these are charged particles.
7. α rays consist of such positively charged particles whose mass is 4 times that of Hydrogen atom and they carry a charge twice that of a proton i.e., the α particles are in fact the nuclei of Helium.

Beta (β) rays

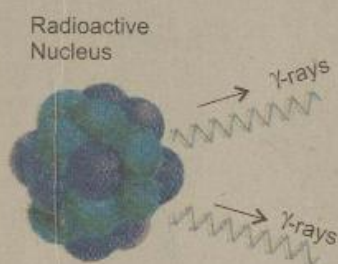
1. β rays are emitted by the radioactive elements with great speed. Their speed ranges from one percent to 99% that of speed of light. The speed of all the β rays emitted by one element is not the same.
2. β rays produce ionization in air, but this ionization is nearly 1/100 times less than that produced by α rays. Although the speed of β rays is very high, since their mass is very small, hence, their energy is less as compared to α -rays.



Emission of α particle from the Nucleus



Emission of β particle from the Nucleus



Emission of γ particle from the Nucleus

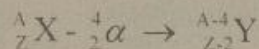
3. β rays affect photographic plates but the effect produced by β rays is much higher than that produced by α particles.
4. They produce fluorescence in Barium platinocynide.
5. They can pass through a thick layer of matter. For example they can easily pass through one centimetre thick sheet of aluminium.
6. β rays are affected by electric and magnetic fields.
7. β rays carry negative charge. The mass and charge of β rays is equal to the mass and charge of an electron. So we can say that β rays are electrons which are emitted by the nucleus.

Gamma (γ) rays

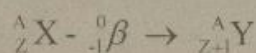
1. They move with the speed of light.
2. The ionization produced in a gas by them, is very small as compared to α or β rays.
3. γ rays affect photographic plates but this effect is much higher than that of β rays.
4. γ rays also produce fluorescence in Barium Platinocynide.
5. The penetrating power of γ rays is much higher than the β rays and they can easily pass through 30 cm thick sheet of iron.
6. They are not affected by electric and magnetic fields.
7. γ rays are such electromagnetic waves which are emitted by the nucleus.

18.3 HALF LIFE

We have already studied that radioactive elements continuously emit radiations, due to which they change into new elements. For example if an α particle is emitted by an element ${}^A_ZX$ then,



${}^{A-4}_{Z-2}Y$ is a new element. Similarly, if β - particle is emitted by an element, then



It is changed to ${}^A_{Z+1}Y$. The atomic mass number of the newly produced element remains the same, but its charge number increases by one unit. It is due to the fact that protons and neutrons are present inside the nucleus, which continuously change into one another. When a neutron emits a β - particle, it changes into a proton. So the charge of the new element is greater by one unit.

In such a reaction, the original element is called the parent element and the newly formed element is called the daughter element. The number of breaking atoms is proportional to the number of atoms left in that element. This means that the number

number of atoms left in that element. This means that the number of initially breaking atoms is large, which decreases with time.

An indefinite time is required for completing the breaking process of atoms in radioactive elements.

The half life of an element is that time during which the number of atoms of that element are reduced to one half.

For example, if the Half life time of a radioactive element is T , then at the end of this time the number of atoms in this element remains one half, after a time $2T$, the number of atoms remains 25% and after time $3T$, the number of atoms are reduced to 12.5% of the initial number.

Example 18.1: The half life of krypton is 3.16 minutes. Out of 100 g of krypton, how much will be left after 9.48 minutes?

Solution:

Total quantity of krypton = 100 g

Half life of krypton = $T = 3.16$ minutes

The 9.48 min. are $\frac{9.48 \text{ min}}{3.16 \text{ min}} = 3T$

The remaining quantity of krypton after first $\frac{1}{2}$ life, $T = \frac{100}{2} = 50$ g

The remaining quantity of krypton after second $\frac{1}{2}$ life, $2T = \frac{50}{2} = 25$ g

The remaining quantity of krypton after third $\frac{1}{2}$ life, $3T = \frac{25}{2} = 12.5$ g

Stable and Unstable Nuclides

Nuclei which do not emit radiations naturally are called stable nuclei. Generally, most of the nuclei whose atomic number are from 1 to 82 are stable nuclei, but the elements whose atomic number is greater than 82, are naturally unstable. These elements, depending upon their characteristics, emit, all the time, different types of strong radiations and they continuously change from one type of element to another. The stable elements can also be changed into unstable form by bombarding them with neutrons. Such elements are called radio isotopes.

18.4 USES OF RADIO ISOTOPES

Although, all the isotopes of an element chemically behave identically, but every isotope emits radiation due to which it is easy to identify an isotope. It is this characteristic due to which the isotopes are being used in different fields of our life.

Uses in Agriculture

If the seeds are unhealthy, they affect the agricultural yield. So such seeds are exposed to radioactive radiation. Varieties of seeds are prepared which are more resistant to the ailments of

crops. Also by using such seeds higher yield is achieved.

Uses in Medicine

Radio isotopes are used to diagnose the various diseases and also for curing some fatal diseases. The radiations from radio active materials are used to diagnose the internal disease of the body without surgery. For example Iodine 131 is used for the study of thyroid glands while phosphorus 32 is used to diagnose the brain tumor.

The parts suffering from cancer absorb more quantity of isotopes, and thus indicate the correct position of the diseased part which helps in the treatment. Some types of cancers are also cured by radio isotopes. For example, radioactive cobalt 60 is used for curing cancerous tumors and cells.

18.5 EINSTEIN'S MASS ENERGY EQUATION

Although in classical physics, the various forms of energy were related under the law of conservation of energy but no relationship was established between the energy and mass. In 1905, when Einstein gave his theory of relativity, it also contained the idea that the energy and matter are interchangeable. For this change an equation was also given which is known as Einstein's mass-energy equation. It is

$$E = mc^2$$

Which means that if mass m of matter is converted into energy, then this will be equal to E , where in this equation c is the speed of light ($3 \times 10^8 \text{ ms}^{-1}$).

Example 18.2: Find the energy produce from 20 kg of carbon if it is completely changed into energy.

Solution:

$$\text{Mass} = m = 20 \text{ kg}$$

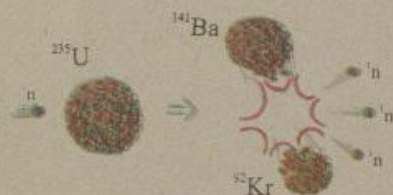
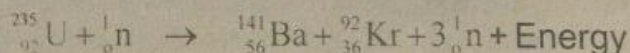
$$\text{Speed of light} = c = 3 \times 10^8 \text{ m s}^{-1}$$

From Einstein's mass-energy equation

$$\begin{aligned} E &= 20 \text{ kg} \times 3 \times 10^8 \text{ ms}^{-1} \times 3 \times 10^8 \text{ ms}^{-1} \\ &= 1.8 \times 10^{18} \text{ J} \end{aligned}$$

18.6 NUCLEAR FISSION

In 1938, Ottobahn and Strassmann bombarded slow neutrons on uranium. As the neutron is a neutral particle, so it was expected that the uranium nucleus will absorb the neutron and become a heavy uranium nucleus. But what happened was, that the uranium nucleus itself broke into two equal parts. In this process two or three neutrons were also liberated. This experiment can be indicated by



Nuclear Fission Reaction

Here Ba and Kr denotes Barium and Krypton respectively.

In this process of breaking a heavy element into two nuclei, large amount of energy is released.

Breaking of a nucleus into two parts with the release of large amount of energy is called fission reaction.

In the fission reaction, when a nucleus breaks, the sum of the masses of the produced nuclei and the neutrons is less than the mass of the original nucleus. This difference of mass results in the release of energy according to Einstein's mass-energy equation.

When a neutron reacts with a uranium nucleus, two or three neutrons are released. Every one of these reacts with next nuclei producing two or three more neutrons and hence, the number of available neutrons and the fission goes on increasing. Such a reaction is called the chain reaction. We have studied that in the fission reaction large amount of energy is released and most of this energy appears in the form of heat. In the chain reaction, as the fission reaction builds up, the liberated energy goes on increasing. The fission reaction thus becomes uncontrollable and hence whole of the matter explodes, which results in great destruction. Such a reaction is used in atomic bomb.

If the fission reaction is controlled, then the desired amount of energy can be produced which may be used in a useful manner. A system in which the fission reaction is controlled is called a controlled fission reaction. In this way the surplus neutrons are absorbed by Boron or Cadmium rods (Fig. 18.3). This is done in a nuclear reactor.

Fusion Reaction

We have already read that breaking of a heavy nucleus into two comparatively smaller nuclei is called fission. Let us now study its reverse process.

Since neutrons and protons are present inside a nucleus, so the total mass of the nucleus should be equal to the total sum of the masses of the neutrons and protons. But when the mass of a nucleus was determined it was less than the total mass of the nucleons. For example, if we determine the mass of a Helium nucleus, it should be equal to the total mass of two neutrons and two protons. We can explain this difference in mass by Einstein's mass-energy equation. If the deficiency of mass is m then energy mc^2 will be liberated on the formation of the nucleus.

If an atom of deuterium is fused with an atom of Tritium then a Helium nucleus or α particle is formed.

This process is expressed by the following equation:

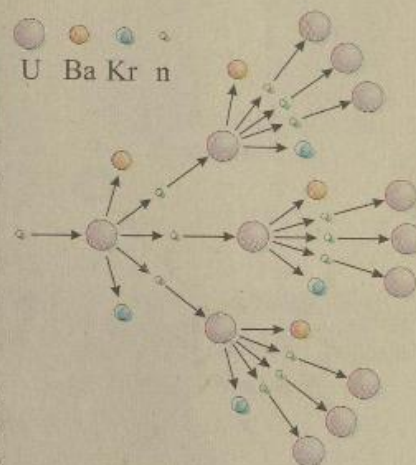
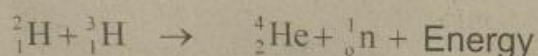


Fig. 18.2: Fission Chain Reaction

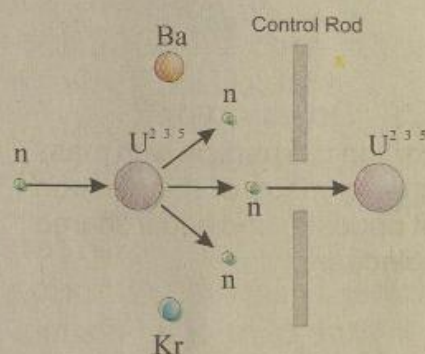
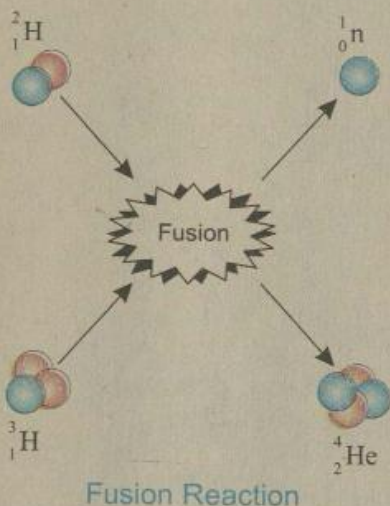


Fig. 18.3: Controlled Fission Reaction

A reaction in which a few small nuclei diffuse to form a heavy nucleus is called the fusion reaction.

More energy is released in the fusion reaction as compared to the fission reaction. In a fusion reaction if isotopes of Hydrogen form a Helium nucleus, nearly 17.6 MeV of energy is liberated. But it is very difficult to produce a fusion reaction. When nuclei are brought near each other for fusion, work has to be done against the electrostatic force which requires great amount of energy or heat. For the fusion reaction the required temperature is achieved by exploding a fusion bomb i.e., an atom bomb inside a hydrogen bomb. Efforts are being made to achieve energy through fusion reaction for peaceful purposes. If the scientists succeed in controlling the fusion reaction, then we will be able to get an infinite store of energy without radiation hazards.

It is considered that the energy coming from the Sun and the stars is due to the fusion of nucleons. For producing α particles i.e., the hydrogen is converted into Helium because the temperature inside the Sun is very high. For example the temperature at the centre of the Sun is nearly 20 million kelvin whereas it is nearly 5 million kelvin at the surface. Bethe had suggested a chain reaction taking place inside the Sun. According to this reaction when 4 Hydrogen nuclei fuse together to form a Helium nucleus, then along with two positron and three α rays, nearly 25.7 MeV of energy is also released. This reaction is responsible for the solar and sateller energy.



Do you know?

Positron is a particle with mass equal to mass of the electron but opposite and equal charge of electron.

18.7 RADIATION HAZARDS

We have already read that radiations are very useful in many ways for mankind. Radiations are being used in different ways in medical, agriculture and in some industrial units, but there is always danger of radiation hazards due to carelessness in its use. The problem is that these radiations are not visible and their adverse effect also do not appear at once. The cells of a human body are destroyed due to the ionization property of the radiations. Although this property is used to destroy the cancerous cells, but the use of radiations in a quantity greater than required, destroy the healthy tissues as well, due to which there is always a risk of cancer or of some other incurable diseases.

Precautions to Minimize Radiation Dangers

The most effective way for saving ourselves from the dangers of radiation is to use the radioactive materials carefully and also by using the instruments which detect the radiations.

- (i) Since the radiations spread in all directions, so one should stay away from its source.
- (ii) During treatment the doctors should use the radiations for the minimum possible time.
- (iii) One should be very careful in using the radiations. After diagnosing the proper part of the body, it should be exposed to radiation carefully by calculated amount.



Symbol of Radioactivity

- (iv) The nuclear waste must be buried in the desert far away from the colonies or in the sea.
- (v) A thick wall of concrete may be built around the reactor in order to protect from its radiations.
- (vi) The radioactive material must be placed in a box of lead.
- (vii) In order to find the intensity of radiations, film badge and dosimeter must be used. It also helps to find whether the quantity of radiation has not exceeded the required amount.
- (viii) The persons working in the laboratories, where radioactive material is available should get themselves medically checked regularly.



Film Badge

SUMMARY

1. Atomic structure: There are two parts of an atom. Its central part is called the nucleus and the neutrons and protons present inside it are called the nucleons. The nucleus is positively charged and the electrons revolve around it in nearly circular orbits.

2. Atomic Number: The number of protons present inside a nucleus is called the charge number or the Atomic number and it is denoted by the letter Z .

3. Atomic Mass Number: The sum of neutrons and protons present in a nucleus is called its Atomic Mass number. It is denoted by the letter A .

4. Isotopes: The elements which have same atomic number but different atomic mass number are called Isotopes.

5. Natural Radioactivity: The elements whose atomic number is greater than 82

naturally break. The natural process of breaking of the elements is called Natural Radioactivity.

6. Half Life: The time during which the atoms of an element are reduced to one half is called the half life of that element.

7. Radio Isotopes: The Isotopes which emit radiations are called Radio Isotopes.

8. Nuclear Fission Reaction: The breaking of a heavy nucleus into two nearly equal parts with the release of large amount of energy is known as Nuclear Fission.

9. Fusion Reaction: A process in which the light nuclei diffuse to form a heavier nucleus is called Fusion reaction.

10. Einstein's Mass Energy Equation: $E = mc^2$, i.e., if the mass of body is m , it is equal to the energy E , where c is the speed of light.

QUESTIONS

- 18.1** What is the difference between Atomic number and Atomic Mass number? Explain.
- 18.2** What is a radio Isotope? Which radiations are emitted out of them?
- 18.3** Describe the properties of α and β rays.
- 18.4** What do you mean by Half life? Explain.
- 18.5** What is meant by fission chain reaction? How it can be controlled?
- 18.6** What is fusion? What is the source of Solar Energy?
- 18.7** How radio Isotopes help us in our daily life?
- 18.8** Fill in the blanks.
 - (i) The charge on particles is _____ time that of Hydrogen nucleus.
 - (ii) _____ in the reaction, two lighter nuclei combine to form a heavy nucleus.
 - (iii) The time in which the number of atoms of a radioactive element is reduced to _____ is called Half Life.
- 18.9** Put a ($\checkmark$) on the correct answer of the given questions:

- (i) An α particle contains:
(a) Two neutrons (b) Two protons
(c) Two neutrons and two protons.
- (ii) Beta particles are actually
(a) Protons (b) Neutrons
(c) Electrons
- (iii) α rays passing through a gas produce
(a) Evaporation (b) Ionization
(c) Excitation
- (iv) The particle which is not affected by electric and magnetic fields is called
(a) α particle (b) β particles
(c) γ particles.

18.10 The Half life of radium is 1600 years. How much of 120 g of radium will be left after 4800 years?

18.11 Half life of Uranium is 4.47×10^9 years. In how much time only 10 g will be left out of 40 g?

18.12 Find the mass of a body from which 1.35×10^{15} J of energy is obtained.

In this chapter you will learn:

1. Electronics and its importance.
2. Analogue and digital electronics.
3. Semi-conductors, P-type, N-type materials.
4. P-N Junction or semi-conductor diode.
5. Semi-conductor diode as a rectifier.
6. Introduction to transistors.
7. Basics operations of digital electronics and gates.
8. Simple uses of logic gates.

19.1 ELECTRONICS AND ITS IMPORTANCE

Electronics is that branch of applied physics which discusses those principles and ways by means of which we control the flow of the electrons using diodes, transistors and other semi-conductor devices in order to meet our various requirements.

Our household appliances such as radio, television, hi - fi sound system, video and audio cassette recorder and players provide us entertainment and all types of information. The various automatic machines as robot, telephone and mobile phone have rendered our work easier. The use of the electronic calculator has become so common that even a shopkeeper uses it for his arithmetical calculations.

Electronic devices have been installed in artificial satellites orbiting the Earth which, by means of electromagnetic waves, keep their contact with Earth. These satellites are designed to serve world wide communication network, to scan Earth's natural resources and to provide us data on weather and climate.

The biggest achievement of electronics is computer which has taken the whole world into its grip. By using the facility of internet, provided by computers, we can contact any institution of world and get the required information. Now-a-days computers are being used even for shopping purposes. By E-mail we can immediately communicate anywhere in the world. Computer is the pivot of the whole information technology. Computer's influence is increasing to such an extent in our life that in near future a person without the knowledge of computer would be considered as illiterate.

This brief introduction would have given you an idea about the importance and usefulness of electronics. Now we would study about electronics, its building block and how do they work.



A microchip equal to size of thumb nail has about one thousand electronic devices.

19.2 ANALOGUE AND DIGITAL ELECTRONICS

We can divide electronics into two main branches: one is analogue and the other is digital.

Those quantities whose values vary continuously or remain constant are known as analogue quantities. For example, the temperature of air varies continuously during 24 hours of a day. If we plot a graph between time and temperature recorded at different times, we get a graph as shown in Fig. 19.1. This graph shows that the temperature varies continuously with time. Therefore temperature is an analogue quantity. Similarly time, pressure, distance etc., are analogue quantities. The part of electronics consisting of such circuits which processes analogue quantities, is called analogue electronics. For example the public

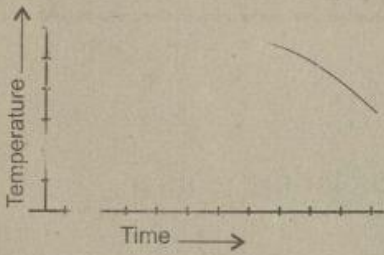


Fig. 19.1

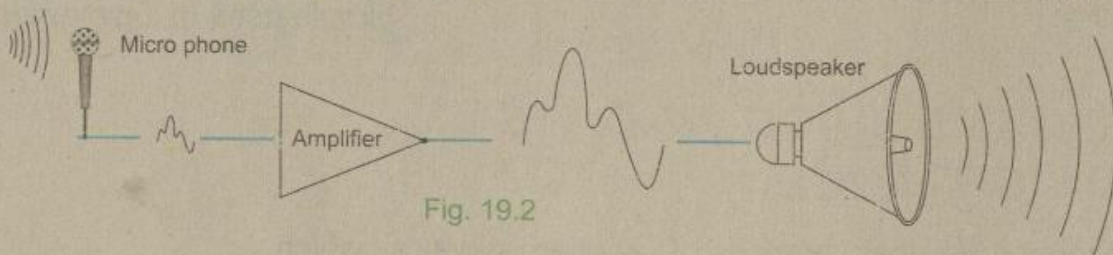


Fig. 19.2

address system shown in Fig. 19.2 is an analogue system in which the microphone converts sound into a continuously varying electric potential. This potential is an analogue signal which is fed to an amplifier (Fig. 19.2). Amplifier is an analogue circuit which amplifies the signal without changing its shape to such an extent that it can operate a loudspeaker. In this way loud sound is produced out of the speaker.

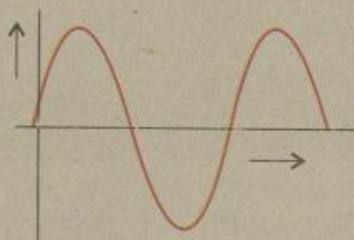
Now we take up digital electronics. The computer operates by counting the digits. The word digit has adopted from this mode of computer's operation. That part of electronics which provides the data in the form of a maximum and minimum voltage signals having no continuous variations, is known as digital electronics. In contrast to an analogue signal, Fig. 19.3 shows a digital data. It can be seen that it has no continuous variation. For quite a long period the use of digital electronics was limited to computers only but now-a-days its application is very wide spread. Modern telephone system, radar system, naval and other systems of military importance, devices to control the operation of industrial machines, medical equipments and many household appliances are all using digital technology.

In our daily life, the quantities that we perceive by our senses are usually analogue quantities which can not be processed by digital circuits. To resolve this difficulty, a circuit has been designed which converts the analogue signal into a digital one in the form of digits. This circuit is known as analogue to digital convertor, i.e., ADC. When we get analogue signal in the form of digital, we can process it with digital circuit, the output of which is also in digital form. This digital output is converted into analogue form by a circuit known as digital to analogue

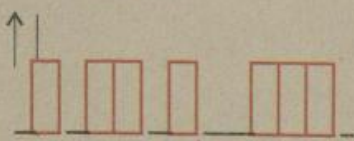
For Your Information



Analogue Watch



(a) Analogue Voltage Signals



(b) Digital Voltage Signals

Fig. 19.3

converter (DAC). As the output of DAC is an analogue signal, it can be readily sensed by us. Thus electronic systems used at present consist of both analogue and digital type circuits.

19.3 SEMI-CONDUCTOR

The material objects, as regards their electrical properties, are classified in three groups:

(i) Conductor

The substances in which electric current flows easily are called conductors. Usually, metals are good conductors. For example gold, silver, copper, aluminum and other metals. Our body is also a good conductor of electricity. Earth is also a very big conductor. In conductors free electrons are present in very large numbers due to which electric current can easily flow through them.

(ii) Insulator

These are the substances through which electric current does not flow. For example mica, plastic, rubber, glass etc. In these substances all the electrons are bound with their respective atoms and cannot move freely. It is because of this reason that the electric current does not flow through them.

(iii) Semi-conductor

These are the substances, whose ability to conduct current at room temperature, lies midway between conductors and insulators. Germanium and silicon are two main semi-conductors. Let us see how these substances develop the property of semi-conductor.

Both germanium and silicon belong to fourth group of the periodic table. As such both of them have four valence electrons. If we examine the cross-section of a crystal of germanium or silicon from front side, we find that its atoms are arranged as in Fig. 19.4(a). The special feature of this arrangement is that each atom is surrounded by four equidistant neighbours as shown in Fig. 19.4(a). Fig. 19.4(b) shows these atoms along with their four valence electrons. It can be seen that each central atom has eight electrons instead of four in its outermost orbit. It is so because it has four valence electrons of its own and four from its neighbouring atoms, one from each. As such it has eight electrons in its orbit. In this way, each atom has eight electrons in its outermost orbit. We know that if the outermost orbit possesses eight electrons, it represents a stable configuration and the electrons do not change this stable state as if they are bound in the orbit. This binding force due to which the electrons are not allowed to leave the orbit is known as covalent bond as shown in Fig. 19.4(c).

In this way all the valence electrons present in crystals of silicon or germanium are bound in their orbits by covalent bonds and no free electrons are available for the flow of electric current. So a crystal of germanium or silicon in its pure form behaves as an insulator. This situation occurs near zero kelvin temperature. At ordinary temperature the electrons have a kinetic motion due to thermal kinetic energy. The motion of some of the electrons is so vigorous that the covalent bond is unable to keep them in their orbits. Such electrons break their covalent bonds and get free, leaving behind the vacancy for an electron in the orbit as shown in Fig. 19.5. This vacant place for an electron in the orbit is

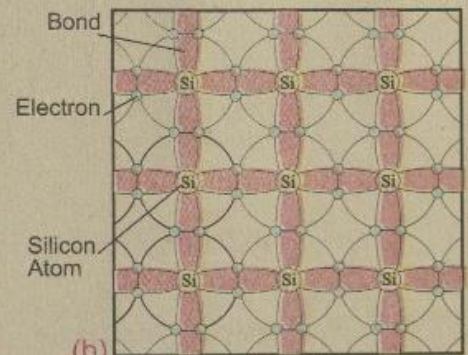
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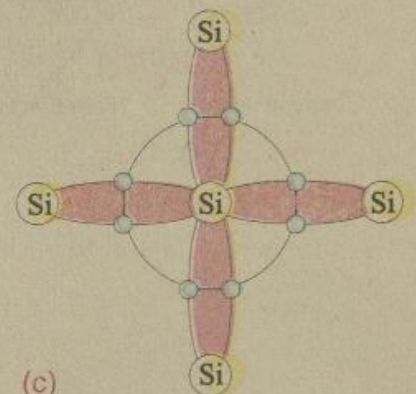
Digital Watch



(a)



(b)



(c)

Fig. 19.4

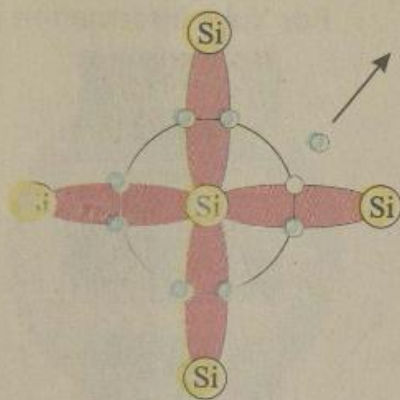


Fig. 19.5

known as a hole. Whenever a covalent bond breaks, it creates an electron-hole pair. It is worth noting that in addition to free electrons, electric current also flows due to holes. Whenever electron from a certain location moves to fill a hole, a hole is created at that particular location. When an electron from other place moves to fill this hole, a hole is created at that place. In this way electrons begin to move because of the presence of holes. This motion becomes a means for the flow of current. Thus, at ordinary temperature, a crystal of germanium or silicon becomes a semi-conductor due to presence of free electrons and holes. It is a semi-conductor because the number of free electrons and holes present in it is much smaller as compared to the number of free electrons in a conductor.

19.4 DOPING

A semi-conductor, in its purest form is not such a good conductor, so it is of little practical value. But it can be rendered useful by increasing the number of holes and free electrons according to our requirement. This is done by adding specified quantities of a trivalent or a pentavalent atoms as impurity while a single crystal of silicon or germanium is being grown. This drastically increases the current conducting properties of germanium or silicon. The impurity added crystal are of two types-one is n-type and the other is p-type.

19.5 N-TYPE SEMI-CONDUCTOR

When a pentavalent impurity such as arsenic(As), phosphorous (P), bismuth (Bi) or antimony (Sb) is added to crystals of silicon or germanium, the number of free electrons increases in it. The impurity is usually in the ratio of $1:10^8$ i.e., for 10^8 atoms of silicon or germanium there is one atom of the impurity. Such a germanium or silicon crystal is known as n-type semi-conductor. Now let us see that how the process of adding impurity increases the number of free electrons. Take the example of silicon crystal doped with antimony. In Fig. 19.6 an antimony atom surrounded by four silicon atoms is shown.

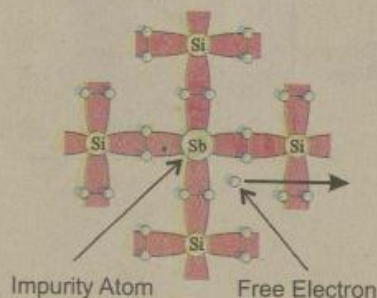


Fig. 19.6

Antimony, being a pentavalent atom, has five valence electrons. Four of them get bound by forming covalent bonds by sharing one electron from each of the four silicon neighbours. But the fifth electron of antimony atom does not find any electron from its four neighbours to form a covalent bond. As such it becomes as free electron. Thus, each impurity atom gives birth to a free electron. This increases the number of free electrons a compared to pure crystal. By controlling the number of impurity atoms during doping, the required number of free electrons can be obtained. In a n-type semi-conductor, current passes mostly due to free electrons.

19.6 P-TYPE SEMI-CONDUCTOR

If a trivalent impurity atom such as aluminium (Al), indium (In), boron (B) or gallium (Ga) is doped while preparing

single crystal of germanium or silicon, the number of holes in these impure crystals is much greater as compared to the number of holes in pure crystal. Such doped semi-conductors are known as p-type.

Take the example of a crystal of silicon which is doped by an aluminium atom. Fig. 19.7 shows aluminium as impurity atom with its four silicon neighbours. Aluminium being trivalent, has three valence electrons which form covalent bonds by sharing one electron from each of its three silicon neighbours. But the aluminium atom does not provide any electron for sharing to its fourth neighbouring atom. Thus a vacancy for an electron is created here as if a hole has been formed (Fig. 19.7). As every impurity atom creates a hole, therefore the number of holes in such crystals is much larger as compared to that in a pure crystal. In a p-type semi-conductor, nearly the whole of current passes due to holes.

19.7 P-N JUNCTION

If a crystal of silicon or germanium is doped in such a way that its one part becomes n-type and the other p-type, then a p-n junction would be formed in between. On one side of this junction, there would be a region of n-type having free electrons as majority charge carriers. On the other side of the junction, there would be a region of p-type having holes as majority charge carriers as shown in Fig. 19.8. In this figure, the black dots show electrons which being free, are moving randomly. While small circles represent holes. The holes do not have a random motion. They move while remaining in their respective orbits.

Just after the formation of p-n junction, some of the electrons of n-type region, due to their free random motion cross the junction and enter into the p-type region where the holes are in abundance. When an electron reaches the site of a hole, it fills up the vacant site and becomes a part of the orbit of impurity atom, having that hole. The impurity atom, with its three valence electrons was a neutral atom, but when an electron fills the hole present in its orbit, then the number of electrons in its orbit becomes four. In this way this atom is converted into a negatively charged ion. Note that in a crystal, every atom has a fixed seat, so the negative ion does not move from its place. In this way, as more and more electrons enter into the p-region from the n-region, a layer of immobile negative ions is formed in the p-region.

Now let us observe the changes which take place in the n-region as the free electrons leave this region. This region contains pentavalent impurity atoms which have five valence electrons in their last orbit. Four of these electrons are bound by covalent bonds while the fifth one is free. As this electron leaves its parent atom and enters into the p-region, the number of electrons in this particular impurity atom gets short by one due to which it is converted into an immobile positive ion. In this way as more and more electrons enter from n-region into p-region, a layer of positive

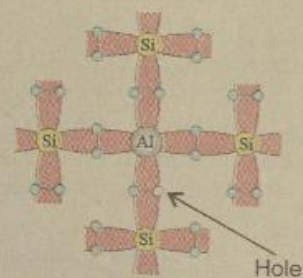


Fig. 19.7

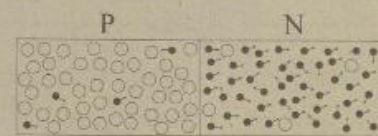


Fig. 19.8: P-N Junction

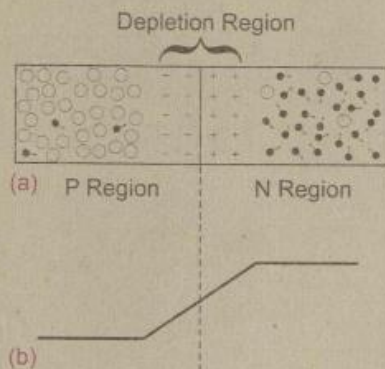


Fig. 19.9

ions, adjacent to the junction, is formed in the n-region.

These layers of positive and negative ions formed just across the junction in the n and p-regions are shown in Fig. 19.9. These layers of positive and negative ions create a potential difference across the sides of the junction. Therefore, a positive potential appears at the n-type side of the junction and a negative potential appears at the p-type side of the junction. This potential difference tends to stop the motion of electrons from n-region to p-region. As the electrons continue to cross the junction from n to p-region, the layer of positive and negative ions across the junction becomes wider. This also increases the potential difference created by these layers till it reaches to such a value that it completely stops the entry of the electrons from n to p-region. As this potential difference does not allow the electrons to cross the junction from n to p-region, so it is known as potential barrier (Fig. 19.9b). In case of silicon its value is 0.7 volt and in case of germanium its value is 0.3 volt.

The region of the layers of positive and negative ions across the junction does not contain free electrons or holes, so it is known as depletion region (Fig. 19.9 a).

19.8 SEMI-CONDUCTOR DIODE

When the p and n-regions of a p-n junction are connected to metallic wires and enclosed in a glass or a metallic case in such a way that only the wires connected to n and p-regions project outside the case, then such an encapsulated p-n junction is known as a diode. Its p part is known as anode and n part as cathode as shown (Fig. 19.10-a). Fig. 19.10(b) shows the symbolic representation of a diode.

Under ordinary conditions, no current passes through a diode due to its internal potential barrier. If an external potential source, for example, a battery is connected across the junction so that current begins to flow through it, the diode is said to be forward biased. For this two conditions are to be satisfied.

- (i) The p-junction or the anode of the diode is connected with the positive terminal of the battery and its cathode with the negative terminal of the battery as shown in Fig. 19.11.
- (ii) The potential of the battery should be greater than the potential barrier of the diode so that the battery could provide the requisite amount of energy to charge carriers present in the p-n junction to overcome the potential barrier.

A specific amount of current is allowed to flow through a diode. If the current passing through the diode exceeds this specific value, the diode gets heated and is likely to be damaged. Therefore, in the biasing circuit of Fig. 19.11, a resistance R has been shown which limits the current passing through the diode within its specific value.

When a diode is forward biased, the width of its depletion region decreases. It means that the quantity of positive and negative ions present in the depletion region becomes less due

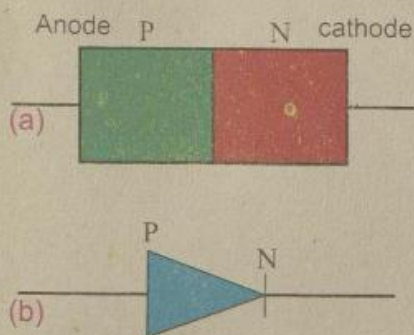


Fig. 19.10

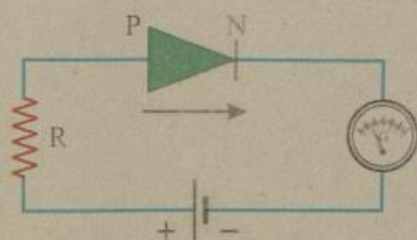


Fig. 19.11

to which the potential barrier also gets low and the current begins to flow easily through the junction. In this situation, the resistance of the junction is only a few ohms. In Fig. 19.12(a), the depletion region of an unbiased diode has been shown by dotted lines, whereas that of a forward biased diode has been shown by ordinary lines. Similarly, in Fig. 19.12(b), the potential barrier of an unbiased diode has been shown by dotted lines, whereas that of a forward bias diode has been shown by ordinary lines.

Reverse Biased Diode

When the p part of the diode, i.e. its anode is connected with the negative terminal and its cathode with the positive terminal of a battery, the diode is said to be reverse biased as shown in Fig. 19.13(a). In this state, the current passing through the diode is nearly zero and we can say that in general, no current flows through a reverse biased diode. It is because of the fact that in reverse biased state, the width of the depletion region increases due to which the potential barrier becomes so high that the charge carriers are unable to overcome it. Therefore, no current passes through the junction. In this state, the resistance of the junction or the diode becomes equal to several mega ohms. Like Fig. 19.12, the depletion region and potential barrier of a reverse biased diode is shown in Fig. 19.13(b, c).

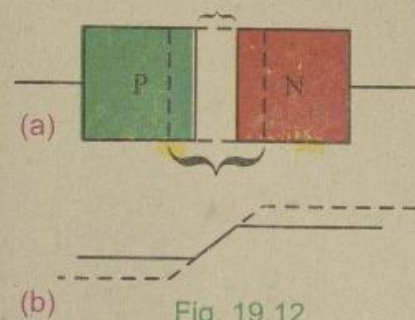


Fig. 19.12

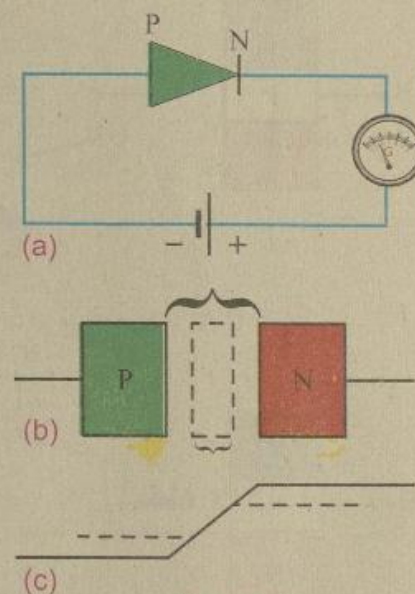


Fig. 19.13

19.9 SEMI-CONDUCTOR DIODE AS A RECTIFIER

Ordinarily electricity is provided to us in the form of alternating voltage but most of electronic devices operate by direct current (D.C). Therefore, it becomes necessary that we convert the alternating voltage to D.C. The process of converting alternating voltage into D.C. is known as rectification and the device used for this purpose is known as rectifier. Fig. 19.14(a) shows a diode used as a rectifier.

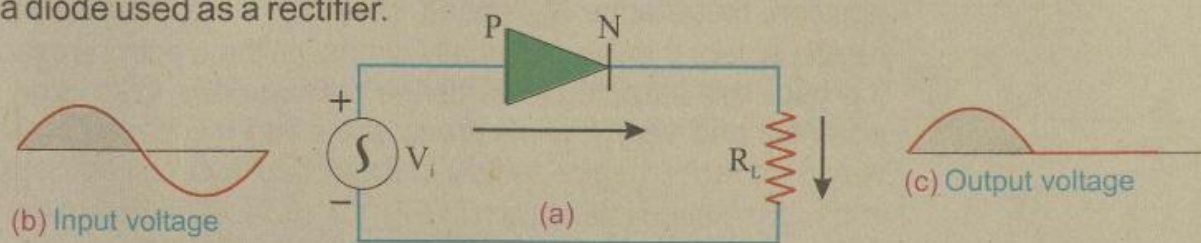


Fig. 19.14

V_i is the input alternating voltage by which we want to pass a direct current through the load resistance R_L . During the positive half cycle of the input voltage, the anode of the diode is at a positive potential, therefore, the diode is forward biased and the current easily passes through the diode and flows through the load resistance R_L . The direction of the flow of the current has been shown by the signs of arrow in Fig. 19.14(a). As the resistance of the diode in forward biased condition is very small as compared to R_L , therefore almost the whole of input voltage appears across R_L as shown in Fig. 19.14(c).

During the negative half cycle of the input voltage, the

anode of the diode is at a negative voltage, so it is reverse biased and it does not allow the current to pass through the load resistance R_L . Therefore, the voltage across R_L remains zero as shown in Fig 19.14(c). Thus the current through R_L passes only in one direction and the voltage developed across it is also uni-directional. In this way, a diode acts as a rectifier.

19.7 TRANSISTOR

If a crystal of germanium or silicon is doped in such a way that n-type regions are formed at its two sides with a very thin p-type region in between, it forms a n-p-n transistor. Alternating the crystal can be formed such that it can have p-type regions at the two sides with a thin n-type region in the centre. Such a transistor is known as p-n-p transistor. Both these types of transistors along with their symbols are shown in Fig. 19.15.

The central region of the transistor is known as base and the regions on its either sides are called emitter and collector. In Fig. 19.15 these regions are shown by letter B, E and C respectively.

Transistor Action

It can be seen in Fig. 19.15 that a transistor consists of two junctions. One is the emitter base junction (EB) and the other is collector base (CB). Generally the emitter base junction is forward biased, while the collector base junction is reverse biased. The biasing scheme for a n-p-n transistor has been shown in Fig. 19.16. The potential V_{CB} that reverse biases the collector base junction is many times larger than the potential V_{EB} that forward biases the emitter base junction.

As the base emitter junction is forward biased, so its resistance gets very low and a stream of electrons is injected from the emitter into the base. Thus current begins to flow through this junction. Resistance R_E is used to control this current. As the base region is very thin, so practically almost all the electrons injected into the base are attracted towards the collector due to its large positive potential and very few electrons enter into the base circuit. In this way a current I_C begins to flow in the collector circuit and a current I_B in the base circuit as shown in Fig. 19.16. As it is the emitter current I_E , injected from the emitter into the base, which is actually divided into the collector current I_C and base current I_B , therefore,

$$I_E = I_C + I_B$$

Note that in Fig. 19.16 direction of current is that of electronic current. The importance of the transistor is based upon the fact that value of the collector current I_C is many times greater than the base current. So by applying a small voltage V_i in the base circuit, if I_B is changed slightly, then the collector current I_C changes significantly. This gives rise a big change in potential V_o across the resistance R_C . Thus a small change V_i in the base circuit, after increasing many times, appears as a voltage V_o in the collector circuit. In this way the transistor acts as an amplifier.

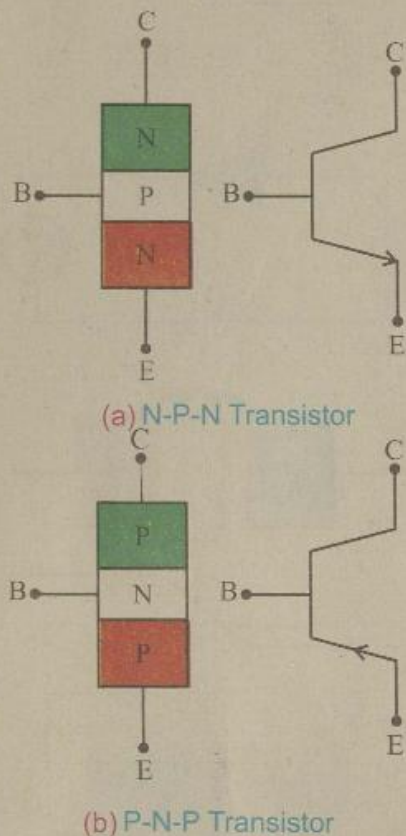


Fig. 19.15

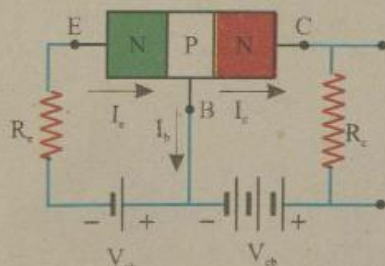


Fig. 19.16

19.11 BASIC OPERATIONS OF DIGITAL ELECTRONICS

There are many things which have only two possible states. For example a circuit can be either on or off. It cannot have a third state. Similarly, a given statement would be either true or it would be false. The given answer of a question would be either right or it would be wrong. A switch would be either open or closed. Such things which can have only two possible states are known as Boolean variables. The two states of Boolean variables are usually represented by the digits 0 and 1. For example, a closed switch is represented by 1 and an open one by 0. If there are two switches and we say that they are in state 1, then it would mean that both of them are closed. Suppose we form a circuit by connecting some resistors, two switches and a battery. As a result of this connection, some current may pass through the circuit. So we call the current in this case as out put. This output also has only two states. Depending upon the states of the switches, the current either would pass or it would not pass. Thus the output current is also a Boolean variable. In case the current is passing, we can say the value of output is 1 and it is zero when no current is passing. Whether the value of the output would be 1 or 0, it depends upon the values of Boolean variables which specify the state of the switches. In this example, the switches form the input Boolean variable because the value of output depends upon the state of these variables. Now the question arises that if the values of input variables of a circuit or a system are known, then how can we determine the value of the output. In order to solve this problem, digital electronics requires three basic operations known as AND operation, OR operation and NOT operation. Let us see what are these basic operations?

Table 19.1

A	B
0	0
1	0
0	1
1	1

19.12 AND OPERATION

In order to understand AND operation, we consider input variables A and B as two switches. There are four possible states of these two switches which are given below:

- i. Both A and B are open i.e., $A = 0, B = 0$
- ii. The switch A is closed and B is open i.e., $A = 1, B = 0$
- iii. The switch A is open and B is closed i.e., $A = 0, B = 1$
- iv. Both switches A and B are closed i.e., $A = 1, B = 1$

The four possible states of the switches A and B are given in table 19.1. A circuit is formed by connecting these two switches in series as shown in Fig. 19.17. Whether a current would pass through the circuit or not, it depends upon the state of the switches. In this circuit A and B are two input variables. Whereas the current passing through the circuit is the output variable X. Its values would be 1 when bulb connected in circuit glows showing that current is passing through the circuit. But the value of X would be 0 when the current through the circuit does not flow and the bulb would not glow.

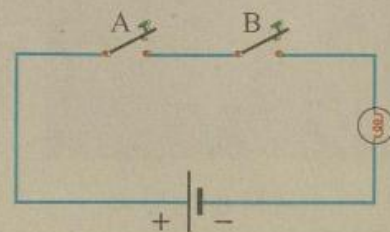


Fig. 19.17

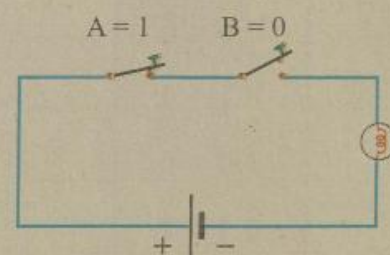


Fig. 19.18

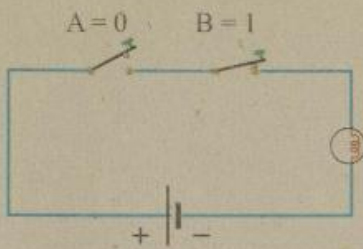


Fig. 19.19

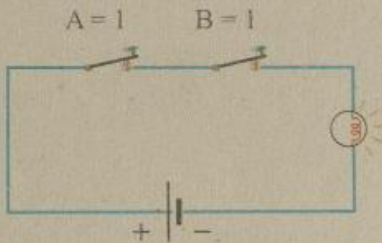


Fig. 19.20

Table 19.2

A	B	X
0	0	0
1	0	0
0	1	0
1	1	1



Fig. 19.21: AND Gate

Table 19.3

0.0 = 0
0.1 = 0
1.0 = 0
1.1 = 1

Now we would find out the value of the output X for all possible values of the input variables A and B as given in Table 19.1.

- i. In the first line of the table $A = 0$, $B = 0$, i.e., both the switches are open (Fig. 19.17). In this condition, no current would pass through the circuit, so the value of X would be 0.
- ii. In second line of the table, $A = 1$, $B = 0$, i.e., switch A is closed and B is open (Fig. 19.18). In this condition no current would also pass through the circuit and $X = 0$.
- iii. In third line of the table $A = 0$, $B = 1$ i.e. switch A is open and B is closed (Fig. 19.19). No current would pass through the circuit, i.e. $X = 0$.
- iv. In fourth line of the table $A = 1$, $B = 1$ i.e. both the switches are closed (Fig. 19.20). Now the current would pass through the circuit and bulb would glow. Thus X would be 1 in this case. The value of X for the various values of the Boolean variables A and B is shown in Table 19.2. Whenever two Boolean variables operate in such a way as two switches are connected in series, then their operation is said to be AND operation. So we can define the AND operation to be such a logic operation that its output is 1 only when all the values of its inputs are 1. It is represented by the sign of multiplication or by a dot. Thus the output X obtained as a result of AND operation shown in Table 19.2 is written as $X = A.B$

It is read as "X equal A AND B". Table 19.2 is called as the truth table of AND operation. Truth table shows all the values of the input variables and the value of output for each set of the values of the inputs. By using the sign of AND operation, the various lines of the truth table can be written as in table 19.3. The various operations of Boolean variables are called as logic operations because the various variables used in subject of logic also possess two values. The word "truth" has also been borrowed from this subject.

In digital electronics, the 0 and 1 values of the variables are simulated by two different levels of the potential. Usually 0 is represented as zero or ground potential and 1 by 5 volts or by any other suitable voltage. Then such circuits have been designed which implement the various logic operations. These circuits are known as logic gates.

The circuit which implements the AND operation is known as AND gate. Its symbol is shown in Fig. 19.21. It has two or more than two inputs and only one output. It operates in such a fashion that the value of its output is always in accordance with the truth table of AND operation; i.e., the value of its output is only 1 (5 volt) when all of its inputs are at 1 (5 volts). For all other values of the inputs the output would be zero.

19.13 OR OPERATION

If we connect two switches A and B in parallel combination and make a circuit as shown in Fig. 19.22. The value of the output current X in this circuit will depend upon the state of the

switches A and B, i.e., upon the value of the input variables A and B.

In this case, the Boolean variables A and B will have a set of four possible values as shown in Table 19.4. According to the values of A and B in each line of this table, a circuit has been drawn in the Fig. 19.23 (a, b, c, d). It can be seen in this figure that the value of X is 0 only in the state when A= 0 and B= 0. In all other states, the current flows through the circuit and the value of X is 1. In Table 19.4, the value of output X is written for all possible values of A and B. This is the truth table of OR operation. We can define OR

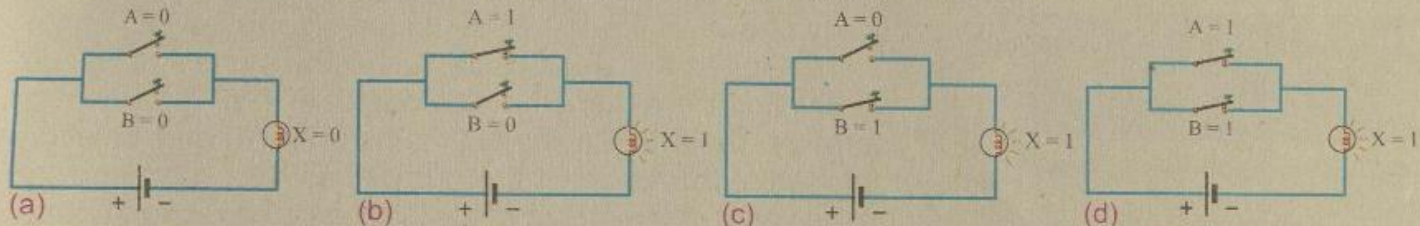


Fig. 19.22

Fig. 19.23

operation to be that in which the output has a value 1 when at least one of its inputs is at 1. The output is 0 only when all the inputs are 0.

OR operation is represented by the plus sign(+). The value of X in the table 19.4 would be written as

$$X = A + B$$

It is read as X equals to A OR B. By using the symbol of OR operation, the various lines of the truth table of OR operation can be written as in Table 19.5. The electronic circuit which implements the truth table of OR operation is known as OR gate. It is symbolically shown in Fig. 19.24. It has two or more than two inputs and has only one output. It operates in such fashion that its output is at 1 (5 volts) even one of its input is at 1 (5 volt). The value of its output would be 0 only when all of its inputs is at 0. In other words the value of its output is in accordance with the truth table of OR operation.

Note that although the symbol of OR operation is the same as the plus sign, yet its operation is quite different from the action of plus sign. For example, we would write the fourth line of the truth table of the OR operation as $1 + 1 = 1$

19.14 NOT OPERATION

A Boolean variable, after NOT operation changes its state and acquires the second possible state. For example, if the value of a Boolean variable is 0, then after NOT operation it would change to 1. Similarly if its value is 1, then after NOT operation, it would be 0. Thus NOT operation inverts the value of Boolean variable.

If the value of a Boolean variable, after NOT operation becomes X, then it is symbolically written as

$$X = \bar{A}$$

NOT operation is represented by a sign of bar and it is read as X equals A NOT. Table 19.6 is the truth table of NOT operation. The electronic circuit which implements NOT operation is known as NOT gate. It is symbolically represented in Fig. 19.25. It has only one input terminal and only one output terminal. It operates in

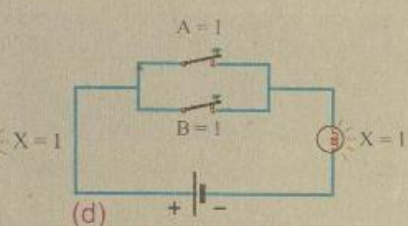
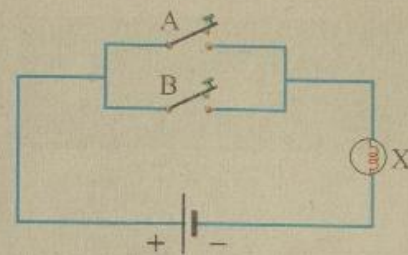


Table 19.4

A	B	X
0	0	0
1	0	1
0	1	1
1	1	1



Fig. 19.24: OR Gate

Table 19.5

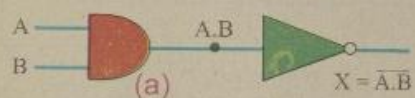
$0 + 0 = 0$
$0 + 1 = 1$
$1 + 0 = 1$
$1 + 1 = 1$

Table 19.6

A	$\bar{A}$
0	1
1	0



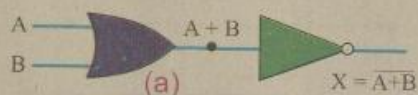
Fig. 19.25: NOT Gate



(b) Fig. 19.26: NAND Gate

Table 19.7

A	B	$x = \overline{A.B}$
0	0	1
0	1	1
1	0	1
1	1	0



(b) Fig. 19.27: NOR Gate

Table 19.8

A	B	$x = \overline{A+B}$
0	0	1
0	1	0
1	0	0
1	1	0

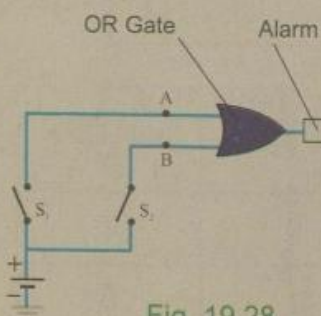


Fig. 19.28

such a fashion that if its input is 0, its output would be 1. Similarly if the input is 1, then its output would be 0.

19.15 NAND GATE

A NAND gate is formed by coupling a NOT gate with the output terminal of an AND gate as shown in Fig. 19.26(a). The NOT gate inverts the output of the AND gate. The output of the NAND gate equals $\overline{A.B}$ and it is written as $X = \overline{A.B}$.

It is read as X equals A AND B NOT. The NAND gate has been symbolically shown in Fig. 19.26(b). In this figure, the NOT gate has been replaced by a small circle, i.e. in the symbol of NAND gate, the small circle attached at the output of AND gate shows NOT operation. Table 19.7 is the truth table of NAND gate. In each line of this table, the value of the output has been obtained by inverting the value of the output of the AND gate corresponding to that line.

19.16 NOR GATE

In this gate the output of OR gate is coupled with a NOT gate as shown in Fig. 19.27(a). This NOT gate inverts the output $A+B$ of the OR gate, i.e., the output of the NOR gate is $\overline{A+B}$ which is expressed by the following equation $X = \overline{A+B}$.

It is read as X equals A OR B NOT. The symbol of NOR gate is shown in Fig. 19.27(b). Table 19.8 is the truth table of NOR gate. In this table, the value of output has been written by inverting the output of OR gate.

19.17 USES OF LOGIC GATES

Logic gates are used to perform different types of jobs in digital electronics. Here we will describe one of its uses.

House Safety Alarm

Suppose there is a room in a house which has one door and one window. We require that whenever a person opens the door or window, the alarm starts ringing.

For this purpose, switches are fitted- one each with the hinges of the window and door. This switch is such designed that when the door or window is closed then its output is at 0 and when the door or window is opened, then its output is at 1 i.e. 5 volts (Fig. 19.28).

Switch S_1 is fitted with the hinge of the door in such a way that when the door is closed, the switch is open and its output is 0. As soon as the door is opened, the switch gets closed and its output becomes 5 volt, i.e., it acquires the state 1. The switch S_2 which is fitted with the hinge of window, operates in a similar fashion. The outputs of these switches are connected with the input terminals of an OR gate whose output is connected with an alarm system. The alarm system consists of a relay and a bell. It operates in a way that whenever the output of the OR gate is in 1 state, the alarm system starts working and the bell begin to ring. When the output of OR gate is zero, the alarm remains quiet.

When door and window are both closed, both of the inputs of the OR gate would be in 0 state, so its output would also be zero and the alarm would be quiet. But as soon as the door or window is opened, then one of its input terminals acquires the 1 state. According to the truth table of OR gate, now the output of OR gate would become 1 due to which alarm would continue to start ringing as long as either of the window or door or both of them remain open.

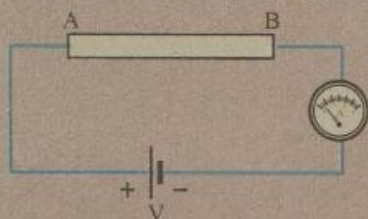
SUMMARY

1. Electronics is that branch of Physics in which different types of work can be performed by controlling the flow of electrons.
2. Those quantities which increase or decrease continuously with time or remains constant are known as analogue quantities. The branch of electronics which processes such quantities is known as analogue electronics.
3. That branch of electronics which processes the data being provided in the form of digits is known digital electronics.
4. Silicon and germanium are called semi-conductor materials because their resistance lies in between the resistances of conductors and insulators.

5. When a pentavalent impurity is added to a pure semiconductor crystal, it is known as n-type semi-conductor. Where as due to the addition of trivalent impurity, it becomes p-type material.
6. A p-n junction is known as semi-conductor diode. In forward biased condition it has very low resistance, whereas in the reverse biased state, its resistance is very high. Hence it is used as a rectifier.
7. Transistor is also a semi conductor device. It is used as an amplifier. Digital electronics is based on three basic operations known as AND, OR and NOT operations.

QUESTIONS

- 19.1 Write an essay on the importance and usefulness of electronics.
- 19.2 Explain the difference between analogue and digital electronics.
- 19.3 Name five analogue and five digital devices that are commonly used in everyday life.
- 19.4 By looking at the following circuit, tell whether AB is a conductor or an insulator.

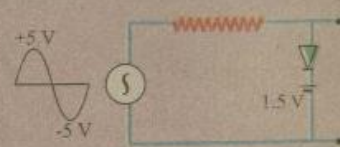


- 19.5 A semiconductor has equal number of free electrons and holes. Is the semiconductor in its most pure form or it has pentavalent impurity?
- 19.6 What is the number of free electrons and holes in a pure semiconductor at 0K?

- 19.7 How the number of free electrons and holes can be increased in a semiconductor?
- 19.8 Why is the potential developed across a p-n junction called barrier potential?
- 19.9 What is the number of charge carriers in the depletion region formed across a p-n junction?
- 19.10 How a diode is forward biased? What is its resistance in this state?
- 19.11 No current is flowing through a diode in spite of the fact that a potential has been applied across its ends. What can be the reason?
- 19.12 Draw the output waveform of the following circuits and explain it.

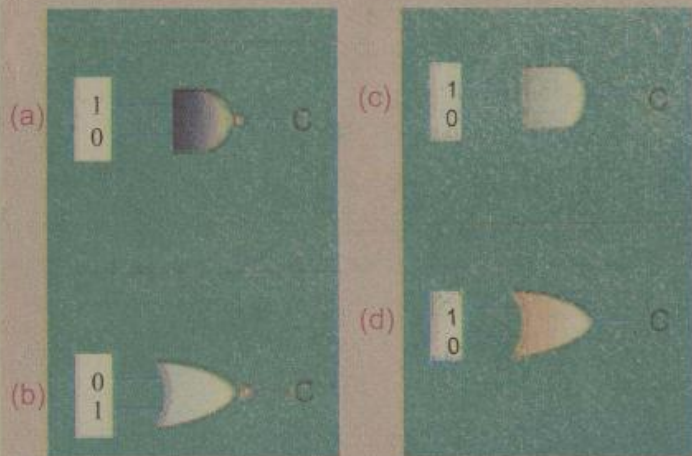


(a)



(b)

19.13 Which of the following gates would have 1 as output.



19.14 Some possible answers have been given of the following questions. Out of these mark (✓) for the correct one.

(i) Atomic number of silver is 47. The number of its valence electron would be ____.

- (a) 1 (b) 7
(c) 8 (d) 18

(ii) In a n-type crystal, the majority carriers are ____.

- (a) holes (b) free electrons
(c) protons (d) positron

(iii) The output of an OR gate would be 0 when

- (a) both of its inputs are 0.
(b) one of its two inputs is zero.
(c) both of its inputs are 1.
(d) any one of its two inputs is 1.

(iv) The output of an AND gate is only 1 when

- (a) both of its inputs are 0.
(b) any one of the two input is 0.
(c) both of its inputs are 1.
(d) Anyone of the two inputs is 1.

(v) The two inputs of a NAND gate are A and B. Its output would be 0 when

- (a) A=0, B=0.
(b) A=1, B=0
(c) A=1, B=1
(d) A=0, B=1

(vi) A and B are the two inputs of a NOR gate. Its output would be 1 when

- (a) A=1, B=1
(b) A=0, B=1
(c) A=1, B=0
(d) A=0, B=0

INFORMATION TECHNOLOGY

In this chapter you will learn:

1. The knowledge about information technology.
2. Communication of information.
3. Information storage devices.
4. The familiarity with word processing, graphics designing and data managing.

The rapid progress in science and technology has broadened the span of informations of the mankind and is enhancing day by day.

The scientific method of storing, arranging informations for proper use and to communicate them to others is called the 'Information Technology (IT).'

Information technology is changing speedily. It is not long ago when the telephone was the only device of communication within the country or abroad. Now-a-days, in addition to telephone, fax machine, computer and internet etc., are the main sources of contact. These sources have brought in contact the whole world. By these devices informations are transmitted in the form of sound, picture and computerised data.

The method that is used to communicate informations to far off places instantly is called "Telecommunication".

20.1 TELECOMMUNICATION

Telegraph was the early form of telecommunication through which messages or informations were converted into electric pulses by a transmitter. The current of these pulses is received very far away passing through wires where these signals comprising electric pulses are converted into audible signals. Latest telecommunication devices are much better and more efficient. These will be studied in this chapter.

Telephone

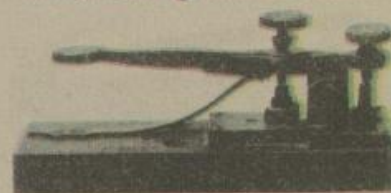
Working principle of a telephone is similar to telegraph but direct conversation can be processed by it. A microphone is fitted in the telephone handset. It changes vibrations produced by conversation into electric signals (Fig. 20.1) which are transmitted



Do You Know ?

Marconi has the distinction that he transmitted the first radio signal in the air.

Interesting Information



Telegraph: The first contact of telecommunication



Fig. 20.1: Telephone

Interesting Information

The speed of sound in air is just 1246 km per hour and it can not go far away from its source. Therefore, it is converted into electromagnetic wave so that they can be sent to far off areas with the speed of light.

Do You Know?

Radio waves are electromagnetic waves.



Fig. 20.2: Fax Machine

Do You Know?

Radio waves travel with the speed of light.



Fig. 20.3: Radio

along a wire to the receiver at the other end of the line. Here an electromagnet and a vibrating diaphragm change the electric signals again into sound. Network of telephone provides a contact between two telephones. In modern network exchange, contacts are made through optical fibre system, microwave transmission or via satellites.

Cellular or Mobile Phone

Radio technology is applied in a mobile phone. It is a type of a radio having two way communication. A mobile phone carries a radio transmitter and a receiver inside it. It sends and receives the messages in the form of radio waves. Our sound waves are converted into radio waves and then reach a nearby station which is linked with the telephone network. The area of each station works as a cell. When a call reaches from one cell to the other, the radio signals emitted by telephone get connected with the next station by an automatic system. Mobile receiver again changes the radio signals into sound.

Another latest form of the telephone is the photo-phone or video-phone. Contrary to a common telephone, speakers can see the pictures of each other. It is the height of electronic communication that the distant speakers feel acquainted with the physical existence of each other.

Telex Machine

Tele printer and exchange machine send the documents through telephone cables by electrical signals to the other telex machine where original print is received. But before converting the document into electrical signals, it has to type on telex machine. Now its use is abolished to some extent.

Fax Machine

Documents of considerable importance are sent from one place to the other through fax machine (Fig. 20.2) with telephone line. Fax machine first gets the reflection of the document like photostat machine, changes it into electronic signal and then transmits it via telephone line. The message when reaches the receiving fax machine, it reproduces the signals in an image print on a paper again.

Radio

Marconi, an Italian scientist succeeded in inventing a radio, about twenty years after the invention of a telephone.

Radio (Fig. 20.3) is such a source of communication in which message is transmitted by electromagnetic waves. At the studio of radio station when a speaker uses microphone for conversation his voice changes into electrical signals. These signal waves are spread all around by a high antenna. When these waves strike the radio aerial, a weak alternating current of the same particular frequency is produced. Similarly waves of some other radio stations also produce currents of their own particular frequencies. Tuning circuit fitted in the radio selects the station waves of the choice and strengthens them. This signal reaches

the amplifier and then the loudspeaker changes the electric signals again into sound. Thus we hear the sound broadcasted from a place hundreds of kilometre away.

Television (TV)

Picture and sound reach us via radio waves or a cable on a TV (Fig. 20.4). At TV station moving pictures and sounds are converted into electric pulses, then their audio video signals are prepared and broadcasted all around by a high antenna, which scatter in all directions in the form of electromagnetic waves. When these waves strike the TV antenna, it produces very weak alternating current of the same frequency. Specific instruments fitted in the TV set separate the sound and picture signals, which are strengthened by the amplifier.

TV tube displays the picture part of the audio video signal on TV screen whereas sound is received through the speakers. Instead of broadcasting, EM waves are sent to a TV set via special wire called 'Cable'. High quality picture and sound is received with the help of a cable.

Computer

Computer is an electronic machine which after analysing and arranging the given information, presents it in a very short time.

All the work is done by the computer in the light of those instructions which are called a 'Programme' and is saved in its memory. Computer preserves this programme and informations in its memory so long as we desire.

The important parts of a computer are given below:

i. Input Devices

In the computer, calculations and instructions are inserted by an input unit. Usually a key board, similar to a type writer is used for this purpose (Fig. 20.5 - a). The different functions of the keyboard are also controlled by a special instrument called a 'mouse'. There are several other methods to feed information into the computer (Fig. 20.5 - b) which include floppy discs and CDs. Input devices send the received data to CPU so that its arrangement and analysis may be done.

ii. Central Processing Unit (CPU)

It is a type of a brain of the computer which performs the whole job. This part comprises of a control unit and a memory unit (Fig. 20.5 - c).

iii. Output Devices

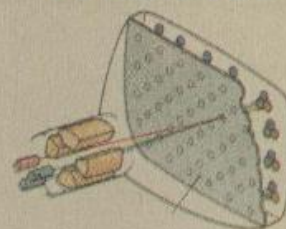
The internal working of the computer is represented by the output unit. It resembles a television set which is called a monitor. All the processes can be observed on its screen (Fig. 20.5 - d) while the print out of the result can be taken on a paper with the help of an attached printer. Moreover output can be recorded on a floppy disc or CDs.

Fast working of the computer, accurate solution of the given information, large memory and capability of deriving results is increases its importance day by day and perhaps, there is no department



Fig. 20.4: Television

Do You Know ?



There are three tubes or electron guns in a colour television set. One of them makes red, second makes green and the third makes blue picture. These are three primary colours of light. All other colours are obtained by mixing these colours and the complete picture is formed on the screen.

(d) Monitor



(c) CPU

(b) Mouse

(a) Keyboard

Fig. 20.5

Interesting Information

The most powerful and swift computer which can send an information in one thousand billionth part of a second is called super computer. It contains many processors.

left where man is not benefiting from its uses.

Internet

Internet is a system with which we can know the global conditions within no time. Not only the informations on internet about the whole world are available but it has revolutionized the communication techniques. This new invention has given a large projection to communication. One can not imagine a speed greater than that by pressing a button you can send your message anywhere in the world. This source of communication is said to be an E-mail. Internet users are provided the facility to send their messages or graphics and the receiver checks them in his spare time. Another important feature of the internet are world websites which is a wide storage of information.

Internet is infact an interconnection of millions of computers. It is neither for one person, nor is the possession of one. It is beyond imagination that a person or a department individually may run the internet. Internet society is a group of many departments which controls the internet. Internet is actually a process using which people can contact each other through computer. This contact is usually made via telephone line or cable. All computers linked with internet use uniform communication process and same code. In the internet terminology, it is called 'protocol' whose name is TCP / IP. It is the abbreviation of transmission control protocol / internet protocol. This protocol controls the transmission and transmits a small portion of the information at a time. This process is repeated millions of times per second.

The language which is used in the internet web is understood well by all the computers linked with it and this language is called HTML which is an abbreviation of Hypertext Markup Language. Computers linked with the internet can exchange their information or can use the data base.

In the beginning internet facility was limited to the government departments or big libraries, but the modern ways of communication have extended this facility. Now-a-days, not only national but at the international level, internet is an important and fastest medium of information.

Students and teachers having contact with the internet can get information of any kind and about any subject. Businessmen can advertise their product by it. Doctors can exchange latest informations about medical problems. In short, information concerned with every department can be obtained from the internet.

Remote Control System

It is an extremely useful instrument. The function of a television and some other electronic machines can be controlled by it from a large distance without any cable connection (Fig. 20.6). Infra red radiations are used to operate it. When any button placed at its panel is pressed, the bulb in control circuit generates a

Interesting Information

Internet is a global web of more than one million nets in which more than 50 million computers are operating and almost 200 million people participate throughout the world. The number is increasing day by day. Contact can be made at any time during the day or night on internet.

Interesting Information

The concepts of space and time are changed in the business due to so many facilities on the internet. Now-a-days, the companies do not work at "office or home" but do work at any place. Computer, fax machine, mobile phone, net works and E-mail are such inventions which have evolved the concept of portable work place for business. Due to these facilities, your office is present where ever you are.



Fig. 20.6: Remote Control Unit

particular binary code signal. This signal emits, from a light emitting diode called LED, an infra red radiation of the same particular code.

When these radiations fall on a lens fitted in a television or any other electric machine, then a photo transistor attached with the lens identifies and sends them to a circuit which decodes the binary signal and issues the order accordingly. Thus we can control the function of the television or other appliances from a far off distance by a remote control system.

Information Storing Devices

The world's information in the form of encyclopedia has been printed on paper, but the information is increasing so rapidly that to get some information from it or to control its weight and volume has become very difficult. So the trend has increased to use such methods which do not use paper. So audio-video tapes, compact discs, laser discs, floppy discs and hard discs are in use for storing information. These devices can store a huge amount of informations in a very small space. We can benefit from anyone of the devices as we require. Usually storage devices work on the principle of magnetism whereas laser technology is used in CD's.

Audio and Video Cassettes

Audio cassettes consist of a tape of magnetic material (Fig. 20.7), on which sound is saved in a particular form of a magnetic field. For this purpose microphone changes sound waves into electric pulses which are made by an amplifier. Magnetic tape of the cassette is moved through the head of audio cassette recorder which is in fact an electromagnet (Fig. 20.8 a). Change of current in the wire wrapped on the electromagnet causes a change in the linked magnetic field. Thus magnetic tape is magnetized in a particular form according to rise and fall of current. In this way sound is stored in a specific magnetic pattern in this tape (Fig. 20.8 b).

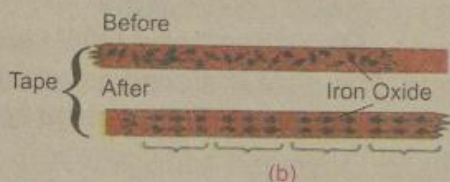
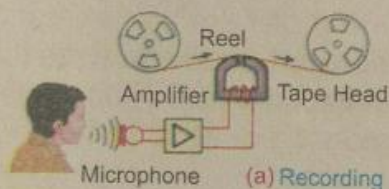


Fig. 20.8

To produce the sound again the tape is moved past the play back head (Fig. 20.8 c). Changes in the magnetic field on the tape induces alternating current signals in the coil wrapped on the head. These signals are amplified and sent to the loudspeakers which reproduce the recorded sound.

In video tape (Fig. 20.9) pictures are recorded along with sound.

Compact Disc (CD)

Compact disc (Fig. 20.10) is a digital disc. Instead of wavy grooves, a pit pattern is formed on it. This pattern comprises of billions of pits of varying lengths and spaces set on a shiny disc. Their arrangement depends upon the variation of sound. Shiny

Do You Know ?

1. In early days, iron wire was used to store magnetic field in the magnetic records.
2. In modern records, magnetic particles are coated on plastic tapes.
3. Now ferric tapes on which iron oxide is used are replacing the old tapes.
4. Chromium oxide is also used on the chromium tapes.
5. The tape consisting of iron particles is called metal tape.



Audio Cassette Recorder and Player



Fig. 20.7: Audio Cassette

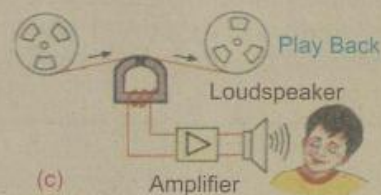


Fig. 20.9: Video Cassette



Fig. 20.10: CD

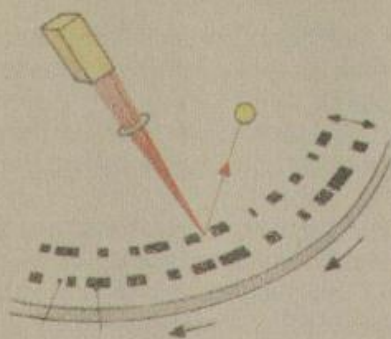


Fig. 20.11

area between two pits is called a 'flat'. Pit pattern can be read by a laser beam (Fig. 20.11). Laser beam is focused on a track, it moves slowly across whole of the disc and the flats reflect the beam whereas pits do not. Thus after reflection when beam touches the head it indicates 1, hence the decoder receives a digital signal which changes it in to a continuously varying electric current. It is then sent to an amplifier and the loudspeaker.

Computer data is also stored in the CD's. While using CDROM (Read only Memory) in computer data is only read and it can not record. While reading the data, computer head does not touch CD. That is why it is durable. Its storage capacity is many times greater than the floppy disc. About 650 MB (mega bite) data can be stored in it. It is packed in a box so that environmental pollution may not affect it.

Movies can be stored in CD's which can be displayed on the computer or TV screen.

Floppy Disc

Floppy disc (Fig. 20.12) is made of flexible plastic which is coated with ferromagnetic compound. The disc is housed in a protective jacket having several holes cut in it which perform as given below.

1. Write Protect Notch

If write protect notch is opened, data can not be entered on the disc and no alternation can be done in the previous data. If the slot is sealed then data can be entered on the disc and alterations can also be done in it.

2. Central Hole

Floppy get fixed on a rotating rod or the spindle and can revolve.

3. Index Hole

Near the central hole is located a small hole used to identify the starting position of the track.

4. Read / Write Hole

Disc drive head R/W using this hole can read and write the data. The data is stored on about 2 cm strip of the disc. Floppy disc can store a data of about 1.44 MB.

Hard Disc

Hard disc is installed inside the system unit. It is made of aluminum and hence it is not flexible. It is enameled with a layer of a material. (Fe, Co, Kr, Ni) that can be magnetized easily. Hard disc has higher speed and larger capacity as compared to other discs. This disc is also called the storage disc. Using this disc and by a control board a large number of informations can be read and written.

Hard disc is made by joining many plates. This disc revolves, in enclosed box, with great speed about an axis (Fig. 20.13). To keep in a closed jacket is to avoid exterior pollution. Because of its large capacity it has high density of data compared to other discs.

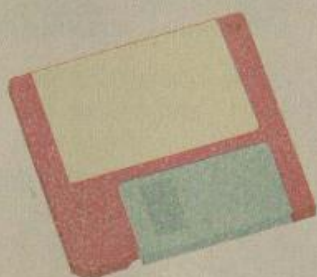


Fig. 20.12: Floppy Disc

Take Care

It is essential to save floppy disc from heat, magnet and water otherwise the stored data on it can be damaged.



Fig. 20.13: Hard Disc

Word Processing

Word processing is such a use of computer through which we can write letters, prepare reports and books. Word processing is a computer programme. By means of this we can develop any document, see it on the screen after typing. Edit it, add some new text or delete the previous text or do the amendments in it. Document can be stored in memory and its print can also be taken. By means of modern word processing, we can write it in different styles and in different colours. We can also use graphics.

In computers this facility is also available which points out the spellings or grammatical mistakes. The content list and index etc. can also be made easily.

To type something 'by computer's keyboard, to correct, to arrange, to amend the document, to add and delete the written portion when required is called 'the word processing'.

Graphic Designing

The process to draw a required line or pictures on a computer screen using mouse or keyboard is called the graphic designing.

Designs of the buildings or components can also be drawn with the help of computers. This process is named as computer aided designing (CAD). Three dimensional (3D) coloured pictures can be drawn by this process which can be checked by rotating it at different angles. Moreover different colours can also be selected for the pictures. This process because of accuracy and comfort is very popular in industrial field.

Data Managing

To collect all informations regarding a subject for any purpose and to store them in the computer in more than one inter linked files which may help when requires needed, is called 'data managing'. The educational institutions, libraries, hospitals and industries store the concerned information by data management. Additions and deletions are made in the data according to the requirement, which help in the improvement of the management of the institutions.

In big departmental stores and super markets optical scanners are used to read, with the help of a Laser Beam, to read the Bar Codes (Fig. 20.14) of a product which indicates the number at which this product is recorded in the register. In this way the detail about its price is obtained and the central computer monitors the bills and the related record of the sold goods. It also helps placing the order for goods being sold in a large quantity and to decide about less selling goods.

Do You Know ?

If the CD is made of metal, it is called hard disk and if it is made of soft elastic material then it is called floppy.

Electronic Banking

Now-a-days , home banking is operating on telephones .You can find your bank balance from the bank on phone,can pay all kinds of bills and transfer your funds by pressing a key of your personal identification number . The bank computer , after your identification , send you all required information. With the help of ATM machines ,you can draw money at any time you want.

Interesting Information

A research is being done at Massachusetts Institute of Technology (USA) to which three dimensional graphics can be shown floating in the space like real objects.

Bar Code



Fig. 20.14: Bar Code Scanning

SUMMARY

1. The scientific method used to store informations, to arrange them for proper use and to communicate them to others is called information technology.

2. The means of transmission of information to far off places is called 'Telecommunication'.

3. Telephone changes sound into electrical signals and sends to the receiver which changes these again to sound by a fitted system in the receiver.

4. Radio transmitter and receiver are fitted inside the mobile phone. It sends and receives the message in the form of radio waves.

5. Fax machine and the telex machine are the means to send the documents from one place to the other.

6. Radio is an instrument which transmits the sound to us.

7. We get sound and picture from a TV.

8. An electronic machine which possesses the characteristics of producing accurate solution of the given information,

excessive and lasting memory and making quick decision is called a computer.

9. Now-a-days, internet is the major source of world communication.

10. An instrument which controls the function of a TV and other electronic machines without any cable connection is called a remote control system or only the remote control.

11. In information storing devices audio cassettes, video tapes, compact disc, laser disc, floppy disc and hard disc are included.

12. By keyboard of a computer to type something, to do corrections, additions or deletions in the documents is called word processing.

13. To draw figures by computer without using drawing material is called the graphic designing.

14. To collect information for a special purpose and to store it in a computer in a file form, which may help at times when needed, is called data managing.

QUESTIONS

20.1 What do you mean by information technology? What sources are in use for it?

20.2 What does telecommunication mean? What are the means of telecommunication? Describe at least two means?

20.3 What is a computer? What do you know about types of computer and its parts?

20.4 Describe in detail about the information storing devices, floppy disc and hard disc. What is the main difference between the two?

20.5 Write briefly about word processing and graphic designing.

20.6 Given statements are true or false. Mark (✓) for true and (x) for false.
i. Document is not typed on telex machine to convert it into electrical signals. (T/F)

ii. Information about every field can be obtained from internet. (T/F)

iii. Floppy disc is made of soft and flexible plastic. (T/F)

iv. Only lines can be drawn on computer screen in graphic designing. (T/F)

v. Data managing helps only in three departments. (T/F)

20.7 Give brief description:

- i. What is the main difference between telephone and cellular phone?
- ii. Why cable TV is preferred?
- iii. In internet terminology, what is meant by protocol?
- iv. Why compact disc and hard disc are housed in a jacket.

20.8 Fill in the blanks.

- i. Radio waves speed is _____ than the sound wave speed.
- ii. In mobile phone _____ technology is used.
- iii. _____ is the brain of a computer.
- iv. Information storage devices work on the principle of _____.
- v. Soft and flexible disc is called _____.
- vi. To get a design on the computer screen by moving a pointer with the help of a mouse is called _____.

20.9 Mark (✓) on the right answer of the following questions:

a. What is fitted in a telephone receiver?

- i. Electromagnet
- ii. Diaphragm
- iii. Electromagnet and diaphragm.

b. Which waves are the radio waves?

- i. Electric waves.
- ii. Electromagnetic waves.
- iii. None of these.

c. Which of the following reasons increase the importance of computer?

- i. Speedy
 - ii. Long time storage of memory
 - iii. Quick decision
- I. (i and ii)
 - II. (ii and iii)
 - III. (i, ii and iii)

Books for further study

Name of Book	Name of Author/Authors
1. Physics	David Sang
2. New Lower Secondary Science	Tho Lai Hoong & Ho Peck Leng
3. Lower Secondary Science I & II	Singapore
4. Physics for you	Keith Johnson
5. Coordinated Science (Physics)	Marry Jones & Philip Marchington
6. Physics	Jim Breithaupt
7. Physics	John D. Cutnell
8. Balanced Science	Jone and Marchington
9. College Physics	Vincent P. Coletta
10. Nuffield Coordinated Science	Nuffield Project
11. Science Quest-4	Graeme Lofts
12. Heinemann Science-3 & 4	Malcolm Parsons, C. Watson
13. New Certificate Physics	L. E. Folivi and A. Godman
14. O-Level Physics	A. F. Abbott
15. Physics	Nuffield Chelsea Curriculum Trust
16. Exploring Physics	Tom Duncon
17. Conceptual Physics	Paul G. Hawiti
18. Fundamental of Physics	Peter J. Nolan
19. GCSE Physics	Tom Duncon
20. Coordinated Science Physics	Stephen Pople and Peter Whitehead
21. Science Insight	Michael Dispezio & Others

GLOSSARY

Alternating current: A current whose direction changes continuously.

Ammeter: An instrument used to measure the current in a circuit.

Analogue electronics: Name of processing quantities of continuous increase, decrease or remaining constant.

Antinode: Points of maximum amplitude of stationary waves.

Atomic mass number: Total numbers of protons and neutrons present in the nucleus.

Atomic number: Number of protons present in the nucleus.

Audio cassette: Device of collecting sound.

Capacitance: Quantity of that charge due to which the potential of a conductor increases by one volt.

Centre of curvature: The centre of that spherical surface whose part is the mirror.

Chromatic aberration: Defect of any lens produced due to dispersion of light.

Compressional waves: Waves in which particles of the medium vibrate parallel to the direction of the wave.

Computer: A machine which can communicate and analyse information efficiently and has a vast and long last memory.

Concave mirror: A spherical mirror whose inner thick surface reflects.

Conventional current: The current due to positive charge carries equivalent to negative charge carries flowing in the opposite direction.

Convex mirror: A spherical mirror whose external surface reflects.

Crest: In case of transverse waves the portion of the displacement above the equilibrium position.

Critical angle: The angle in the denser medium whose respective angle of refraction in the rare medium is 90° .

Diffraction: Bending of waves round an obstacle.

Digital electronics: Name of processing data provided in the form of digits.

Direct current: Current which always flows in one direction.

Electric current: The rate of flow of electric charge through any cross sectional area.

Electric field: The space around a charged body in which an other charge experiences its effect in the form of a force.

Electric intensity: The influence of a force acting on a unit positive charge at any place.

Electric lines of force: Lines drawn in the direction of electric intensity in an electric field.

Electric potential: Potential energy of a unit charge in any electric field.

Electric power: Amount of energy obtained from electric current in unit time.

Electromagnetic field: Production of magnetic field due to passage of electric current through a conductor.

Electromagnetic induction: The phenomenon in which e.m.f. is produced due to relative motion of coil and magnet.

Electromagnetic waves: Such waves, which do not require any material medium for their propagation.

Electromotive force: The energy needed to move one coulomb charge through the whole circuit including the battery.

Electronics: The branch of physics in which the flow of electrons is controlled and used according to the need in semiconductor devices.

Electroscope: An instrument used for measuring the nature and presence of charge on a body.

Far sightedness: Defect of eye due to which nearly located objects are not clearly visible.

Fixed capacitor: The capacitor whose plates cannot move.

Floppy: A device used for storing computer data.

Focal length: The distance between the pole and principal focus of any mirror or the distance between optical centre and principal focus of any lens.

Fusion reaction: The phenomenon in which small nuclei diffuse each other to form a larger nucleus.

Galvanometer: An instrument which indicates the current in a circuit.

Half life: The time in which the number of radioactive elements becomes half.

Information technology: Scientific method of collecting and arranging information and impart

- Infrasonics:** Sound of frequency less than 20 hertz, which are inaudible by human ears.
- Intensity of sound:** Energy transmitting per second through a unit area placed perpendicular to the direction of sound waves.
- Interference:** Resultant displacement of two or more than two waves in a medium.
- Internet:** Important source of global contact.
- Isotopes:** Atoms of an element whose atomic number is same but mass number is different.
- Kilowatt hour:** Quantity of that energy which is obtained from one kilowatt power in one hour.
- Laser disc or CD:** A device used to store data with the help of digital technology.
- Magnetic flux:** The number of magnetic lines of forces passing through any surface.
- Magnification:** The ratio to the height of the image to the height of the object.
- Mechanical waves:** Such waves which require a material medium for their propagation.
- Music:** Pleasant and musical sound.
- Mutual induction:** The current induced in the coil by the change of flux in the nearby coil.
- Natural radioactivity:** The natural spontaneous breakage of heavy nucleus.
- Node:** That points of the stationary waves whose amplitudes are zero.
- Noise:** Unpleasant sound.
- N-type semi-conductor:** A semi-conductor in which pentavalent impurity is doped.
- Nuclear fission reaction:** The splitting of heavy nucleus into two parts in which huge amount of energy is released.
- Pitch:** Characteristic of sound due to which shrill and grave sound is distinguished.
- P-N junction:** A semi-conductor diode.
- Pole:** Centre of the mirror.
- Power of lens:** Inverse value of focal length (in metre).
- Principal axis:** Straight line which joins the pole of mirror to the centre of curvature.
- Principal focus:** Point from where rays parallel to the principal axis pass after reflection from a concave mirror.
- P-type semi-conductor:** A semi-conductor in which trivalent impurity is doped.
- Quality of sound:** Characteristic of sound due to which different sounds are distinguished.
- Radio isotopes:** Isotopes which emits different rays.
- Radio:** An instrument which impart sounds to us.
- Rectification:** Conversion of alternating current into direct current.
- Reflection:** Bouncing of waves after striking from the other medium.
- Refractive index:** Ratio of speed of light in air to the speed of light into any other medium.
- Remote control:** An instrument which controls television or electronic equipments by sitting far t.
- Self induction:** The e.m.f. induced in a coil due to change in the current of that coil.
- Semi-conductor:** Elements of the 4th group consisting of silicon and germanium.
- Short sightedness:** Defect of eye due to which distant objects are not seen clearly.
- Simple harmonic motion:** Vibratory motion in which the acceleration of the body is directly proportional to its displacement.
- Solenoid:** Cylindrical coil of the wire having more than one turn.
- Sound:** A form of energy which is transferred from one place to another due to compressional waves.
- Specific resistance:** Resistance of unit length and unit cross sectional area of a conductor.
- Spherical aberration:** Defect of thick and large aperture of a lens.
- Stationary waves:** Waves in which the amplitude of all particles of the medium remains constant.
- Tele communication:** To impart information quickly tot he far areas.
- Total internal reflection:** The reflection of light in the same denser medium from the surface of a rare medium.
- Transformer:** An electric instrument which increases or decreases the value of alternating voltage.
- Transverse waves:** Waves in which particles of the medium vibrate perpendicular to the direction of motion of the wave.
- Trough:** In case of transverse waves, portion of the displacement below the equilibrium position.
- Ultrasonics:** Sound of frequency more than 20000 hertz, which are inaudible by human ears.
- Variable capacitor:** A capacitor whose plates can move.
- Video cassette:** A device used to store sound and picture.
- Voltmeter:** An instrument used for the measurement of potential difference between the ends of a circuit.

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APPEAL

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